U.S. Soil Conservation Service.

The Fifth Annual Meeting

of the

COLORADO RIVER WATER FORECAST COMMITTEE

Los Angeles, Calif.

April 15, 1949

Fort Collins, Colorado
August, 1949

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
DIVISION OF IRRIGATION

TRANSCRIPT OF MEETING

COLORADO RIVER WATER FORECAST COMMITTEE

1006 State of California Building
Los Angeles, California

April 15, 1949

Edited by

Homer J. Stockwell, Associate Irrigation Engineer

UNDER THE AUSPICES OF

Division of Irrigation, Soil Conservation Service

U.S.D.A.

George D. Clyde, Chief
Logan, Utah

Fort Collins, Colorado August 1949

PROGRAM

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FIFTH ANNUAL MEETING
of the
COLORADO RIVER WATER FORECAST COMMITTEE

1006 State of California Building
Los Angeles, California
April 15, 1949

9:00 A.M.	Registration
9:30 A.M.	Opening Remarks
9:40 A.M.	Flow of the Colorado River During the 1948 Season,- John H. Gardiner, U.S.G.S., Tuscon, Arizona.
9:50 A.M.	Discussion
10:00 A.M.	Snow Cover Conditions in Utah - Don Mitchell, Division of Irrigation, SCS, Logan, Utah.
10:20 A.M.	Snow Cover Conditions in Arizona - Clyde E. Houston, Division of Irrigation, SCS, Reno, Nevada.
10:25 A.M.	Snow Cover Conditions in Wyoming - L. C. Bishop, State Engineer Cheyenne, Wyoming.
10:30 A.M.	Snow Cover Conditions in Colorado - H. J. Stockwell.
10:45 A.M.	Snow Conditions in California Fred Paget, California Division of Water Resources, Sacramento, California.
10:55 A.M.	Recess
11:05 A.M.	Forecast of Colorado River Near Grand Canyon, April-July 1948 - U. S. Bureau of Reclamation, Boulder City, U. S. Weather Bureau, Southern California Edison Company, Soil Conservation Service, U. S. Geological Survey, Los Angeles Department of Water and Power, and others.
11:30 A.M.	The Snow Negotiating Jeep - George A. Lewis, Department of Water and Power, City of Los Angeles, California.
11:45 A.M.	Lunch
1:30 P.M.	Forecasting Methods Used by the U. S. Weather Bureau - Wallace C. Lamoreaux, Head, WBFC, Salt Lake City.
1:45 P.M.	Discussion

1:55 P.M. Forecast Methods Used by the Office of River Control and Research Work Accomplished During the Past Year - C. P. Vetter, Chief, Office of River Control, USBR, Boulder City, Nevada.

2:05 P.M. Methods of Predicting Inflow into Lake Mead for Month of July - Frantz R. Lupton, Office of River Control, USBR, Boulder City, Nevada.

2:20 P.M. Operating Water & Power Facilities within Maximum and Minimum Water Limits - Dan Mason, Electrical Engineer, Los Angeles Department of Water and Power.

2:40 P.M. Discussion

2:50 P.M. Recess

3:00 P.M. Practical Techniques Used in Streamflow Forecasting - Marvin Diamond, Office of River Control, USBR, Boulder City, Nevada.

3:15 P.M. Discussion

3:20 P.M. Water Problems on International Streams - Charles D. Curran, Engineer, Office of River Control, International Boundary Commission, El Paso, Texas.

3:35 P.M. Discussion

3:45 P.M. Progress Report from Cooperative Snow Investigations - Forrest L. Rhodes, Program Director, Cooperative Snow Investigations, Oakland, California.

4:00 P.M. Objectives of the Colorado River Water Forecast Committee - Discussion led by George D. Clyde, Chief, Division of Irrigation, SCS, Logan, Utah.

4:30 P.M. Adjournment

Local Arrangements by Harry F. Blaney, Soil Conservation Service, 1509 Post Office & Court House Building,
Los Angeles 12, California

COLORADO RIVER WATER FORCAST COMMITTEE

FIFTH ANNUAL MEETING

ROOM 1006, STATE BUILDING, LOS ANGELES, CALIFORNIA

APRIL 15, 1949

The Meeting was called to order at 9:30 A. M. by Chairman R. A. Work.

CHAIRMAN R. A. WORK: Gentlemen, the fifth annual meeting of the Colorado River Water Forecast Committee will please come to order. It is a privilege to be able to act as your Chairman this morning at the request of Mr. Stockwell. I know it will be a distinct disappointment to you when I have to advise you that Mr. Stockwell advised us yesterday that, due to major illness in his family, he would be unable to be with us this morning.

The first speaker on our program this morning will be Mr. John H. Gardiner, District Engineer of the United States Geological Survey at Tucson Arizona. I take pleasure in introducing Mr. Gardiner.

MR. JOHN H. GARDINER: Mr. Chairman and Members of the Committee: This paper I have is very brief. It is just factual information on the Flow of the Colorado River during the 1948 Season. We attempted to relate the first six months of this year, but, as I explain in this paper, that didn't work out so well. I will just read this to you and give the figures as I go along. The normal run-off referred to in our figures is the median run-off for the twenty-five year period of 1920-1945.

Mr. John H. Gardiner then read the paper entitled "Flow of the Colorado River during the 1948 Season.". See page 32.

CHAIRMAN WORK: Thank you very much, Mr. Gardiner. Mr. Gardiner has given us, now, a springboard, so as to speak. He has given us some values as to the average or normal flow of the Colorado which may be used as a kind of yard-stick to which other estimates can be compared. I would like to know if there is any discussion before we pass on. (None)

Before passing on to the next paper on the program I would like to introduce to you Mr. Blaney who gave Mr. Stockwell very valuable assistance in the arrangement of the program and in securing these local arrangements for us.

MR. HARRY F. BLANEY: I have nothing to say except that I want to thank the representatives of the Southern California Edison Company, the City of Los Angeles, Department of Water and Power, the Metropolitan Water District of Southern California, the California State Division of Water Resources, and others for their cooperation in making this meeting possible. Representatives of some local organizations are unable to attend this meeting because they are attending hearings in Washington, D.C.

CHAIRMAN WORK: In Mr. Stockwell's absence, I will read the paper that he has prepared, describing the scope of the Snow Survey Program on the Colorado River Basin.

..Chairman Work then read the paper "Snow Survey Program on the Colorado River Basin" by Mr. H.J. Stockwell. See page 34.

CHAIRMAN WORK: That constitutes Mr. Stockwell's Progress Report to this Committee. Are there any questions or comments, particularly from the Bureau of Reclamation?

MR. MARVIN DIAMOND: (U. S. Bureau of Reclamation) I might suggest at this time that in regard to the establishment of some of the new courses with the courses that they are planning on discontinuing so that in that case we can have some hope of continuing the snow record of that particular locality. Otherwise, we may lose the complete value of the thirteen years that we have now.

CHAIRMAN WORK: You mean by that, Mr. Diamond, that the courses should be measured simultaneously?

MR. DIAMOND: Yes, especially for a year or two, or maybe three. It is hard to say right now how long we might have to measure them to get some sort of overlapping record between them so we can convert the discontinued snow course into the new snow course, but some effort should be made on that part.

MR. J. W. STANLEY: (Bureau of Reclamation) Mr. Chairman, you made one comment about February 1st measurements. We realize, of course, the many difficulties in getting the measurements on February 1, as well as on the other dates, but, remembering that the snow record, after all, is only about thirteen years in length, it seems that we probably are a long way from the final method in forecasting from snow courses, and it is a little difficult to conclude at this time that there won't be a value from February 1 measurements in combination with other dates or with other data. That, I think, is the reason we have rather wished that the February 1 measurements will be continued. We don't believe we have gone far enough yet to say definitely that they aren't going to be worth anything.

CHAIRMAN WORK: Thank you, Mr. Stanley. Your point of view, Mr. Stanley, would be that snow surveyors , we might say, act as bookkeepers of the water balance, and should keep current records which will serve the needs of all water users on that watershed. In the case of multiple use reservoirs, you require a running inventory at all times, do you not, of the probable inflow to that reservoir?

MR. STANLEY: I think that expresses it rather well, yes. Of course with precipitation records, we can get a look at the outlook even earlier than with the snow record, but it seems that until we are pretty sure that the February first measurements are going to be valueless, we should make an effort to continue them. That is the way we see it at present.

CHAIRMAN WORK: We are glad to get these sentiments from the group, and I know Mr. Stockwell will pay close attention to the recommendations of this group, too. Is there further discussion on that point? (None).

The next paper on the program is a brief résume of Snow Cover Conditions in Utah. This will be the first, now, of several papers des-

cribing snow cover conditions as they now exist through the basin. This discussion will be presented by Don Mitchell, Engineer of the Division of Irrigation, Soil Conservation Service, Logan, Utah. Mr. Mitchell is in charge of snow surveys in Utah. Mr. Mitchell

..Mr. Don Mitchell then presented his paper on Snow Cover Conditions in Utah. See page 36.

CHAIRMAN WORK: If there are no questions, we will proceed to a resume of Snow Cover Conditions in Arizona and in Nevada, to be presented by Clyde Houston, Irrigation Engineer of the Division of Irrigation, Soil Conservation Service, Reno Nevada. Mr. Houston

..Mr. Clyde E. Houston then presented his paper entitled "Snow Cover Conditions in Arizona and Neva da.". See page 37.

CHAIRMAN WORK: Thank you, Mr. Houston. The snow survey work in Arizona and Nevada has been under the direction of Mr. Houston for some time, but beginning this next season there will be a division of responsibility. Mr. Houston will continue in charge of the snow survey in Nevada, but the Arizona survey work will be directed by Mr. Burke Peterson. Burke is an employee of the Division of Irrigation and Soil Conservation Service stationed at Phoenix, Arizona. We are going to call on you, Mr. Peterson, to present a statement of Snow Cover Conditions in Wyoming on behalf of Mr. Bishop, State Engineer of Wyoming, who was unable to be here this morning. I take pleasure in introducing Mr. Burke Peterson.

..Mr. Burke Peterson then read the report "Snow Cover Conditions in Wyoming" prepared by Mr. L. C. Bishop. See page 38.

CHAIRMAN WORK: Thank you very much, Mr. Peterson. Are there any comments on that presentation? (None) Perhaps it would be a good plan to reserve discussion on this phase of the program until we get all our information in on the snow cover.

In Mr. Stockwell's absence, Mr. Mitchell is going to give a brief resume of Snow Cover Conditions in Colorado and extreme northwestern New Mexico, and then I will call on Mr. Harry Potts to supplement Mr. Stockwell's statement.

..Mr. Don Mitchell then presented Mr. Stockwell's paper on "Snow Cover Conditions in Colorado." See page 39.

CHAIRMAN WORK: Thank you very much Mr. Mitchell. We have a letter from John Bliss indicating that he will be unable to get to this meeting, but I believe the information Mr. Bliss might have brought to us has been covered by Don's presentation for Colorado.

Before going on, now, into a statement for California, I am going to ask Harry Potts to give us the benefit both of his personal observations in Colorado and of any other reports that may have come in to him.

MR HARRY POTTS: You refer principally to snow cover, I presume.

CHAIRMAN WORK: Snow cover or soil moisture conditions, or any other information you may care to present.

MR. POTTS: I think that from what I have noticed in regard to the snowfall through Colorado, it is normal or a little better, in most cases. On the South Platte, where I am principally interested in the pack, the pack is about normal, slightly above what we had last year. On the headwater of the Fraser, it is about 115 or 120 per cent of normal. Of course the February, March and April measurements, in my opinion, don't mean a great deal to us. It is really the May 1st measurements that tell us the story, because in most cases we get about sixty per cent of the snowfall between February 1st and the 1st of May. In consequence, I don't start my photographic survey until the first of May.

It appears that we are going to have a little better than normal, although conditions were pretty serious until we had the January storm. In February we had nothing in the vicinity of Denver, but March did pretty well for us and it is considerably above normal in precipitation for the year. Thank you.

CHAIRMAN WORK: Thanks very much Harry. Mr. Paget is unable to be here, but Mr. H. C. Kelly, Senior Hydraulic Engineer of the Water Resources Branch of the State of California has kindly agreed to present for us a picture of conditions in California. Mr. Kelly.

.. Mr. H. C. Kelly then presented the paper entitled "Snow Conditions in California". See page 40.

CHAIRMAN WORK: Thank you, Mr. Kelly. We will throw this meeting open for general discussion now. I think something that we might discuss profitably, would be the effect upon runoff of this possible lack of soil moisture. I would like to ask the gentlemen from the Weather Bureau, Mr. Lamoreaux, Mr. Rupp, or Walter Wilson if they would like to advance any thoughts along that line.

MR VERNON W. RUPP: I don't believe I would be prepared at the present time to give any detailed discussion on that. I think Mr. Wilson is connected with the Laboratory and might be able to give us something on that, or at least indicate something on it.

MR WALTER WILSON: I am reluctant to make any general statement. One of the things I, personally, have learned the last few years about studying snow is the danger of general statements, and I am speaking of the great difference between basins, and also the differences from one portion of the basin to another.

In the two basins where we have made observations, the amount of water stored in the soil in the form of ground water varies from negligible amounts to more than eight inches. In some places, it is extremely important; in other places, it is not.

CHAIRMAN WORK: Mr. Stafford, have you any comments along this line that you would care to offer?

MR. HARLOWE M. STAFFORD: No, I am just surprised at the small amount of soil moisture reported for that area.

CHAIRMAN WORK: I would like to ask you, Mr. Houston, if you have found it expedient this year to change your run-off forecasts from what you might have predicted on the basis of snow cover alone.

MR. CLYDE E. HOUSTON: Yes, but how much I don't know. I agree with Walter that each watershed is absolutely different. In Humbolt in Central Nevada, we found the ground water measurement was low for the period that has been measured. The period of record is about ten years. There is quite a ground water basin out there. The forecast point is below that basin, and we had the Geological Survey man with us on our local forecast meetings and he introduced us to the fact that we haven't yet determined how to use the ground water levels in relation to stream flow forecasts. We did, of course, decrease our forecasts quite a bit because we felt that the greater part of that ground water basin is going to have to be replaced before the water gets past the gauging station. It is a very good point to study, and I don't know, myself, how to go about it, but we are going to try next year.

CHAIRMAN WORK: Are there any further comments?

MR. H. V. PETERSON: (U. S. Geological Survey) I would just like to mention that it seems to me a very good opportunity this year for studying the effect of soil deficiencies and the influence that it might have on run-off. Not that I have any particular basic data or basic figures to present, but to say something about a personal experience, I came back from Washington in February and happened to be amoung those unfortunate ones who got stuck in a train up in Wyoming where I spent six or seven days waiting for the snow to clear up. I came through Salt Lake around the 20th of February and I talked to several people there and to my brother, particularly, who lives near there. He told me at that time that they had about three feet of snow near Logan. Mr. brother was down there a short time ago. I asked him what had happened to the three feet of snow, and he said it has practically all sunk into the gound. There was practically no surface run-off from that three feet of snow. Whether that is due to deficiency in moisture last year or not, I am not prepared to say, but you know that a quantity of water can go into the ground without producing run-off if all the factors relating to the disposal of snow are favorable. I don't know whether measurements have actually been made or not, but it seems to me that there are criteria this year which can be used in determining the effect of soil moisture on your snow run-off.

I heard something of the same thing on the Gila River in Arizona. I happened to be in Arizona around the 1st of March. Prospects were for something of a record run-off in the Gila River. Since that time, the prospects are not nearly as great as around the 1st of March, due to the water sinking into the ground.

CHAIRMAN WORK: We will have a brief recess, gentlemen, and I think we can go into this subject a little further when these forecasts come up for discussion.

..Whereupon the meeting recessed at 10:45 A. M. for ten minutes.

CHAIRMAN WORK: The meeting will come to order, please. The next section of the program, gentlemen, has to do with specific forecasts for the ensuing season of the flow of the Colorado River in the Grand Canyon. We will call first on the Bureau of Reclamation. I expect we should call on you, John, should we not?

MR. J. W. STANLEY: Do you want just the figure?

CHAIRMAN WORK: I would like to have your figures and know how you got at it.

MR. J. W. STANLEY: A couple of the fellows on the program this afternoon can tell you a good deal more about how to get at it. What we consider our official forecast is arrived at on the basis of accumulative precipitation from the beginning of last October to the date of the forecast. The mean forecast figure for the period of April-July is 12,000,000 acre feet, and the range there is 2,900,000 acre feet plus or minus.

I might exp lain that actually, while that is at present our official forecast, our operations will be tempered to some extent by certain forecasts made by other methods. You remember our old March increase of snow water content. Our mean forecast by that method is down to 9,500,000. Combining that March increase with the prior precipitation, we have a mean forecast of 10,700,000, so we consider those other figures in our plans for operations. The normal for a 36-year period is 9,600,000.

CHAIRMAN WORK: Mr. Gardiner gave the normal as 13,400,000.

MR. STANLEY: That is not the same. For our 36-year period, which is a little bit different from Mr. Gardiner's period, it is 9,600,000.

CHAIRMAN WORK: We will write that down. (Writing digures given by Mr. Stanley on the blackboard) Is this 9,600,000 for April-July?

MR. STANLEY: Yes. That is for the 36-year period recorded, so that normal will not be exactly the same.

CHAIRMAN WORK: Thank you, Mr. Stanley. Mr. Lamoreaux, are you going to present the forecast for the Weather Bureau?

MR. WALLACE C. LAMOREAUX: I will have more to say about the method of deriving that after lunch. The forecast is for 11,700,000 acre feet for the water year, and the percentage of normal is 104 per cent. The April-July forecast is for 8,600,000 acre feet.

CHAIRMAN WORK: (Writing figures on blackboard) Next, the Southern California Edison Company. Are you going to give that, Bill?

MR. W. A. LANG: My friend Bill Andree has a different figure from what I have. Neither one of us had a bulletin until this morning. My figure is 11,750,000 for April-July.

MR. W. A. ANDREE: My figure is 11,700,000.

CHAIRMAN WORK: How about the Geological Survey, Mr. Gardiner?

MR JOHN H. GARDINER: I have a figure here, and some background information. I don't know whether you want that or not.

CHAIRMAN WORK: That is fine. Let's put your figure down and then have the rest of it.

MR. JOHN H. GARDINER: The figure is 11,300,000, plus or minus 1,400,000 for April-July.

..Mr. Gardiner then read his report. See page 42.

CHAIRMAN WORK: Thank you very much. Now, the Los Angeles Department of Water and Power.

MR. H. M. KELLY: The forecast is 11,100,000 acre feet. It would be about 125 per cent of the average that we have. That is for April-July.

..Mr. Kelly then read a report. See page 43.

CHAIRMAN WORK: The Program Chairman lists "others". Are there other estimates any of you gentlemen would like to submit? If not, I will add the SCS forecast here. It is 10,900,000 for April-July.

Well, here we have it. (Reading from blackboard)
Estimated April-July Run-off for Colorado Grand Canyon, 1949.

	Acre Feet	
U. S. Bureau of Reclamation	12,000,000 ± 2,900,000	
Southern California Edison	11,725,000	(Approximately)
U. S. Geological Survey	11,300,000 ± 1,400,000	
L. A. Bureau of Water & Power	11,100,000	(125% of 13-year Av.)
Soil Conservation Service	10,900,000	
U. S. Weather Bureau	8,600,000	(11,700,000 equals 104% Normal Water Year)

(Normal equals 9,600,000 - April-July - 36 yr.)

CHAIRMAN WORK: I have listed these in order of descending magnitude, and that is quite a spread from 8,600,000 to 12,000,000--a spread of about 25 per cent.

MR. W. A. LANG: How does the Weather Bureau figure less than normal?

CHAIRMAN WORK: Do you want to enter discussion on this, Mr. Lamoreaux?

MR. LANG: I just happened to notice the figure.

MR LAMOREAUX: I think we will cover that this afternoon, probably.

MR. MARVIN DIAMOND: I just wonder about that Weather Bureau forecast, since it was mentioned we have 2,700,000 for October through March, and 8,600,000 for April-July. That adds up to 11,300,000. That means that August-September may only run around 400,000 acre feet. I wonder if there is a possible discrepancy there?

MR. LAMOREAUX: No. The method used in arriving at that April-July forecast takes into account the antecedent run-off, and there is a little variation in arriving at the method there. It is a procedure that we have been working on, so that, while it is not altogether consistent, there is not too much discrepancy there. I think the August-September run-off runs around a million acre feet.

CHAIRMAN WORK: You are estimating the run-off then for this year at--

MR. LAMOREAUX: Less than normal.

CHAIRMAN WORK: I would like to ask the Bureau of Reclamation if they want to give any amplification of their arrival at their figure, since they are on the high side.

MR. STANLEY: It is 12,000,000 by the method we have been using pretty consistently the last few years. It is simply correlation between accumulated precipitation since last October up to April, correlated against the run-off for April-July. That is all there is to it. The precipitation data that we used are the thirteen stations we have been using. They were arbitrarily selected on the basis of descending order of correlation. We used the top thirteen stations, each of which would individually correlate quite well with the April-July run-off. The precipitation we use then for October through March is average precipitation accumulated at those thirteen stations correlated with the run-off rate for April-July.

CHAIRMAN WORK: It is my understanding, Mr. Stanley, that the program of operation of Lake Mead will be based in the next several months upon the forecast of 12,000,000. Is that correct?

MR. STANLEY: Yes, it will be based on that, with whatever other things it may be necessary to take into consideration. I might mention that this afternoon Mr. Lupton will explain how, as time goes on, we check the run-off as it comes to see how much more we are going to get. We have a method of figuring that.

CHAIRMAN WORK: You revise right along, then?

MR. STANLEY: We don't start revising immediately, but as soon as we can, we start revising to get closer to the figure.

CHAIRMAN WORK: But at the immediate moment, the plans for operation

of Lake Mead are now being based on an anticipated flow of 12,000,000 acre feet?

MR. STANLEY: Let's put it this way: from 9,100,000 to 14,900,000.

CHAIRMAN WORK: That takes a rather flexible operating plan, I presume.

MR. STANLEY: This year, of course, with those figures, there is a lot of water. We have been using the 9,100,000 as the lower limit. It is still a lot of water.

CHAIRMAN WORK: Just as a matter of curiosity, supposing you were to use the figure of 8,600,000, what changes would that make in your operating plans?

MR. STANLEY: You mean if our forecast were 8,600,000?

CHAIRMAN WORK: Yes.

MR. STANLEY: It would mean primarily a smaller production of power for the coming year. Does that answer the question?

CHAIRMAN WORK: I was just curious to know what sort of wheels that forecast would set in motion.

MR. STANLEY: Well, for one thing, if it were fairly sure we were going to get a lower run-off, it would be a simple matter to get down to the flood control level. We get down to the flood control level we require on July 31. It would have been, up to now, probably just as easy to arrive at the flood control level on March 31 if we had been using our ordinary forecast that we used since the first of the year in planning the operation all the way through the year.

CHAIRMAN WORK: If you gentlemen don't object to your chairman pursuing this particular line of thought just a little further--is there any objection to it?--now I would like to ask the Bureau of Power and Light how their plans for the ensuing season would be affected by a difference in the forecast of 3½ million acre feet inflow into Lake Mead.

MR. H. M. KELLY: There is going to be a paper given this afternoon. Perhaps Mr. Mason could give you an answer on that.

MR. DAN MASON: I expect to take that up in some detail, as Mr. Kelly said. It would mean that our generation at Hoover would be cut a great deal, and steam generation increased. There is a balance between the two, and if our expected energy from Hoover were cut down, as it probably would be under such expected in-flow conditions, our steam would have to be increased.

CHAIRMAN WORK: Then you would begin to make plans presumably at once for fuel oil supplies, etc.?

MR. MASON: That is right.

MR. C. E. KODIL: (Dept. of Water and Power) In direct answer to your question as to what changes in plans would be made if the estimate were to be based on 8,600,000 for April-July: The Reclamation Bureau is encouraging the use of as much water as possible at the Hoover Power Plant. If the forecast were 8,600,000, the Reclamation Bureau would probably discourage the use of water. It is a general practice to decide on the figure for the operating year at Hoover, which is June 1 to May 31, in about October or November. Last November, a figure of 5,600,000 kilowatt hours was decided upon as the figure for the current year, on the expectation of inflow of 12,000,000 for next year. The Reclamation Bureau would encourage a decrease for the current year if the estimate were 8,600,000 acre feet for next year, and then they would probably be encouraging us to cut down on the kilowatt hours, rather than increase it.

CHAIRMAN WORK: Thank you. Bill, do you want to add anything?

MR. LANG: No. I would ask Mr. Andree whether he has anything to add.

CHAIRMAN WORK: Mr. Andree, how would the Edison Company modify its plans, assuming the 8,600,000?

MR. ANDREE: I think we would do similarly to the Department of Water and Power. It would mean additional steam at this time. We have steam pretty well at a minimum at present.

CHAIRMAN WORK: I would like to ask you another question now, John, if I may. Assuming you don't get 12,000,000 during April-July, assuming you get 8,600,000 this year during April-July--what gears does that throw out of mesh?

MR. STANLEY: I think it would affect principally the generation schedule for the next contract year, because if something happened up on the watershed that is not indicated in most of these forecasts, the operation would be changed, of course, as soon as we begin to know about it.

MR. VERNON W. RUPP: (U. S. Weather Bureau) In any procedure we have an element of deviation from one year to another. In addition to that, we have an element of error as indicated in these plus or minus figures. Now, if we assume a median forecast of 12,000,000 acre feet, we would have to allow ourselves a plus or minus in our operations to cover ourselves in case the natural or normal deviation cannot come into the forecast figures. We would have to allow something there to operate on and not assume that that forecast was exact. It seems that in any forecast that is made you would necessarily have to allow some latitude because no procedure we have seen so far that has come to our attention is exact.

CHAIRMAN WORK: Yes, and I presume you would have a plus or minus in the 8,600,000.

MR. RUPP: There would be some latitude there.

CHAIRMAN WORK: Which might bring your maximum up to somewhat greater than the Bureau of Reclamation's possible minimum?

MR. RUPP: There would be an overlapping there.

CHAIRMAN WORK: Well, we won't pursue that subject any longer, since it is going to come up in the discussion this afternoon.

It is a real privilege to have you with us this morning, George, and to hear about the work you have been doing with the Snow Negotiating Jeep. Mr. George Lewis.

..Mr. George A.Lewis then presented his paper on "The Snow Negotiating Jeep". Slides were shown. For his remarks, see page 46.

CHAIRMAN WORK: Thank you, Mr. Lewis.

MR. LEWIS: If there are any questions, I will be glad to answer them.

CHAIRMAN WORK: What did you say the pounds per square inch was?

MR. LEWIS: It is 1.3.

MR. HOUSTON: What are the results on sidehills?

MR. LEWIS: We operate only on existing roadbeds. If an ordinary automobile will traverse the road, a jeep will also when the snow is on.

MR. HOUSTON: Do you use four-wheel drive?

MR. LEWIS: We use low-low and both axle drives in snow. We have found it beneficial to control the power as much as possible. You get better results, and then up in that country, snow is not nearly so level as it is presumed to be. Eight or nine miles an hour is pretty fast on a wheel base that short.

MR. STAFFORD: Suppose you are going along and run into a pretty deep drift and your wheels compact, does it push through or does it block?

MR. LEWIS: As I said, the wheels will not spin below axle depth, and the necessity is that you get out in front and, instead of shoveling, you stamp some snow under the wheels. They have never been hung up on the center.

MR. MITCHELL: You mentioned 83 inches of snow. How would the jeep operate in deep snow.

MR. LEWIS: If the depth isn't over thirty inches, you can operate but in soft snow--twenty per cent snow is pretty dry--you can't go over a couple of feet. That is, unless you have an opportunity to compact your road after each storm. We have been successful in keeping the road up because after each storm they go out in the jeep and make one pass. It has a fourteen inch tread so it makes quite a track.

MR. LUPTON: Have you done any experimenting with single tires?

MR. LEWIS: We have tried all combinations. We tried singles. We

used singles for a couple of years, and from that went to the dual construction.

MR. LANG: We have been successful in the use of the jeep, too.

MR. LEWIS: I might add that several agencies have adopted this method, how successfully I don't know, but some have had fairly good luck with it. We have had excellent success.

CHAIRMAN WORK: If there are no further questions, I will call on Jimmie Jones at this time. Mr. Jones spoke off the record.

CHAIRMAN WORK: I would like to urge that any of you who have not signed the register, please do so before you leave for lunch, thus assuring yourself of a transcription of the record. The Committee didn't make any arrangements for luncheon, feeling that in this particular location in Los Angeles we might better all shift for ourselves. Let's try to reconvene promptly at 1:30 P. M. The meeting is adjourned.

..Whereupon the meeting adjourned at 11:55 A. M.

AFTERNOON SESSION

..The Meeting was called to order at 1:30 P. M. by Mr. R. L. Work, Chairman.

CHAIRMAN WORK: The Colorado River Water Forecast Committee will reconvene its Fifth Annual Meeting. Leading off the discussion this afternoon is one of a series of papers devoted to some recent developments in run-off forecasting procedure. The first of those papers, I am sure, will be exceedingly interesting to all of us, as that has to do with the forecasting procedures that have been developed and that are being used by the U. S. Weather Bureau. The paper will be presented by Mr. Lamoreaux, Head of the Run-off Forecasting Unit of the Weather Bureau in Salt Lake City. Mr. Lamoreaux.

..Mr. Wallace C. Lamoreaux then presented his paper on Forecasting Methods used by the U. S. Weather Bureau. See page 50. (Applause)

MR. LAMOREAUX: If there are any questions, I will attempt to answer them.

CHAIRMAN WORK: That was a very interesting presentation, Mr. Lamoreaux.

MR. MARVIN DIAMOND: (U. S. Bureau of Reclamation) I would like to make a few comments, if I may, with regard, primarily, to the use of the double-mass curve technique. I notice that the Weather Bureau makes adjustments according to a base pattern. I think Mr. Lamoreaux did mention that in most cases the change in the double mass curve may coincide with the station move, but quite often it doesn't. The question arises: Do they go ahead and adjust the earlier record just because they have abandoned the double mass curve, regardless of whether there is any change in the history of the station at that time?

Another point that might be brought up is the selection of base stations. Are they checked very thoroughly to see whether they have any bends when each one is plotted against the twenty? Mr. Lamoreaux referred to Marion's paper. He was one of the original investigators of double-mass curve. I would like to refer to his paper for a moment. He investigated in the Susquehanna Valley something like 212 stations. Roughly, out of that 212, he found thirty or forty that might be used in working up his base pattern. He then went ahead and plotted each one of these 212 stations against that base pattern and, to quote Marion, he said, "You can count on the fingers of one hand the number of stations that gave an exactly straight line." In other words, something less than five stations out of 212 gave a straight line when you apply this double mass diagram.

The question then arises; Are we going to, you might say, just relentlessly adjust every station without actually finding out whether there is a real valid adjustment? Did someone put a building up near the rain gauge, or move the rain gauge? Or are we just going to adjust the stations without any good investigation into its past history? I think that is a point that should be considered very carefully by any investigator, especially when he is working with this double-mass diagram technique.

Just one more point on the business of adjusting run-off with reference to the double-mass curve. I think when we think of a time trend in nature most of us would imagine a gradual change. I don't think that nature decides at any one point--maybe in 1929 or 1930--to change things around and from then on have everything be different. We would rather expect a very gradual change. In all probability we might not even notice that change within thirty years, which is really an infinitesimal time limit when we consider time, itself. But the question arises, then, in the adjustment of these run-off records, whether the change in this run-off trend just happens very sharply, just suddenly in 1929, or 1940, or whatever year you want to pick. That is about all I have to say.

MR. LAMOREAUX: The Weather Bureau does make an investigation into the various precipitation stations before the adjustments are made where the records are available. As I pointed out, each individual station is tested against the precipitation base, and if that station is found to have erratic or decided breaks in the slope of the double-mass curve, then that station is omitted and the base is recomputed. The base is considered, and any small irregularities in the individual station is considered to be dampened out by the other stations and compensated for by a number of stations on the base. I am just wondering how you would account for the definite breaks which you find in those double-mass curves or any other assumption. I wonder how you account for the definite bends you find in the relation between precipitation and run-off. I believe the Bureau of Reclamation used similar adjustments up until this present year, didn't they?

MR. DIAMOND: No. Just last year we fiddled with adjustments. We made one, but this year we realized that we couldn't hold it up, and until we feel that any adjustings can be done on a very sound basis, we are not going to do any adjusting. We don't find that it is a sound enough basis to go back and change run-off records.

MR. LAMOREAUX: You admit that they do show us changes in station exposure and location. That is quite definite.

MR. DIAMOND: Yes, and they quite often give bends where the station has never been moved. I can show any number of records for stations on the Colorado River basin which when plotted against, say, the average of thirty-five stations all over the basin, will give bends, and there is no history at all of the station being moved.where the bend occurs. I don't know what causes those bends.

CHAIRMAN WORK: Let me ask the gentleman from the Geological Survey if he has something to offer in this connection.

MR. H. V. PETERSON: I don't think so, but Mr. Troxell might have something to offer.

MR. HAROLD C. TROXELL: We have drawn a few doublemass curves here in Southern California. I am not strong for the double-mass curve. The comparison between two we had was beautiful until we got a monthly precipitation of over ten inches. Then they varied considerably. One gauge always had twice as much during those heavy months, while during the remainder of the period of record, when precipitation was down to three or four inches, they were in almost complete agreement. But if there were three or four wet months together, it built up one station tremendously, and the other didn't show that response.

MR. LAMOREAUX: I don't think anyone will attempt to use these for individual months.

MR. H. V. PETERSON: You don't account for any variation in your summer precipitation?

MR. LAMOREAUX: Summer precipitation is assumed to be normal.

CHAIRMAN WORK: Mr. Lang, are you just looking sleepy or looking skeptical about some of this discussion?

MR. LANG: Just skeptical.

CHAIRMAN WORK: Have you anything to contribute?

MR. LANG: I think the changes in equipment and methods of measuring precipitation and run-off would probably account for some of the bends in the curves.

MR. WALTER WILSON: I would like to offer a brief comment on the relations between precipitation and run-off. Instead of entirely agreeing with Mr. Diamond's statement that such changes are gradual, I would say you are not dealing with true run-off. I think the U.S.G.S. people would be the last ones to deny that they have changed and improved their techniques from time to time, and when these changes in measurement techniques occur, they would be represented by breaks in the record, rather than the gradual shift.

CHAIRMAN WORK: I don't like to limit discussion, gentlemen, but I do believe we had better pass on to the next paper, which is entitled "Forecasts Methods Used by the Office of River Control and Research Work Accomplished During the Past Year." The paper will be presented by John Stanley, Assistant Chief of the Office of River Control of the Bureau of Reclamation at Boulder City, Nevada, for Mr. C. P. Vetter, Chief of that Office. Mr. Stanley.

..Mr. J. W. Stanley then made some remarks on the above subject. These remarks were a summary of papers presented in past year and no formal paper was presented for publication.

MR. STANLEY: That is about the extent of our accomplishments during the past year. I want to tell you that Mr. Vetter was very sorry he couldn't be here, and sorry he couldn't be able to see you all. (Applause)

CHAIRMAN WORK: Would you prefer, John, that discussion be reserved until the other papers by members of your staff are presented?

MR. STANLEY: I think so.

CHAIRMAN WORK: All right. We will reserve discussion until we have heard Mr. Lupton's paper and Mr. Diamond's paper. The next paper on the program is prepared by Frantz Lupton of the Office of River Control, U. S. Bureau of Reclamation, Boulder City: "Methods of Predicting Inflow into Lake Mead for the month of July. Mr. Lupton.

..Mr. Frantz R. Lupton then presented his paper entitled "Methods of Predicting Inflow into Lake Mead for the Month of July." See page 55.

CHAIRMAN WORK: Thank you very much, Mr. Lupton. The next paper on the program will be presented by Dan Mason, Electrical Engineer, from the Los Angeles Department of Water and Power. The title of Mr. Mason's paper is "Operating Water and Power Facilities within Maximum and Minimum Water Limits."

..Mr. Dan Mason then presented his paper entitled "Operating Water and Power Facilities within Maximum and Minimum Water Limits." See page 59.

CHAIRMAN WORK: Thank you, Mr. Mason. I would suggest, gentlemen, that we deviate slightly from the program and go ahead with Mr. Diamond's paper, then throw it open for discussion, and after that, have a recess.

The next paper on the program will be entitled "Practical Techniques used in Streamflow Forecasting" to be presented by Mr. Marvin Diamond of the Office of River Control, of the Bureau of Reclamation at Boulder City.

..Mr. Marvin Diamond then presented his paper entitled "Practical Techniques used in Streamflow Forecasting." See page 65. (Applause)

CHAIRMAN WORK: The meeting is now open for discussion, gentlemen, on the papers by Mr. Lupton, Mr. Mason, and Mr. Diamond.

MR. WALTER WILSON: I would like to say that the things Mr. Diamond just talked about are extremely important. He started out his discussion with the statement to the effect that he was going to talk about statistical methods and that the length of record and those other things applied to statistical methods. I would like to amplify that. I am sure he will agree with me that whenever we perform any operations on any methods we apply statistical methods. Some are more refined than others. Unfortunately, it is difficult to sit here in a stuffy room and follow with interest a discussion such as Mr. Diamond presented, but I will say now that those of us who aren't up on that stuff had better get up on it if we are going to stay in this business.

MR. C. B. JACOBSON: (U. S. Bureau of Reclamation) I would like to comment on Mr. Diamond's paper. He listed a number of items which would cause the double-mass diagram to bend. I think he overlooked another item. That is a change in use which probably occurred during the period of studying, due to new use of water in the basin, a diversion, or depletion upstream.

I might say that in the past the uses in the upper basin probably haven't affected to any appreciable extent the forecasts that are being made at the present time where we forecast the residual flow. In other words, at the present time, it is estimated that there are 2 to $2\frac{1}{2}$ million acre feet of water consumed in the upper basin. Your figure here on the board relating to Grand Canyon is 11,700,000 as a normal flow, 104 per cent of normal, which would put it at, say, roughly ten million acre feet--plus. You will note that 2 to $2\frac{1}{2}$ million acre feet is a considerable percentage of that ten million. In other words, you are forecasting 75 percent of the 100 per cent.

In the upper basin at the present time, there is roughly somewhere around a million acre feet of storage. That million doesn't enter into your present forecast too seriously because it is possibly only ten per cent of the flow. However, it is filled out of the April-July period. As uses will increase in the upper basin--and there is no doubt that they will be stimulated due to the approval of the Upper Basin Compact--the increased uses will be accompanied by hold-over storage. That is, present uses in the upper basin rely to a great extent today on the direct flow diversions. In the future, it will require considerable hold-over storage to affect, particularly, irrigation projects, and also trans-mountain diversion. These hold-over reservoirs will, of course, be filled out of high water season in most instances. Therefore, your forecasts for April-July 2ill be seriously affected if you continue to use the present method. It may be looking a long way into the future, but you can see what would happen when the upper basin is using $7\frac{1}{2}$ million acre feet. In order to use $7\frac{1}{2}$ million acre feet, you may have to deplete the flow two or three times that amount in a year at the reservoir locations, the water being held over as long as twenty years in order to get a uniform delivery through the transmountain diversion, or a uniform use. Of course, that probably won't be so serious at that time, because the flow to the lower basin or to the people in the lower area will no doubt be equated, at least to some extent, so that the forecast of annual run-off probably won't be as important as it is today.

MR. M. B. HOLBURT: I have a question I would like to direct to Mr. Mason in regard to the hypothetical problems set up in his statement. You talked about two additional power allocations the Bureau of Reclamation made. I was wondering if they were sold as secondary power. Also, how is your original amount of firm power determined? Is it done on the basis of this 12,000,000 minus 2,900,000?

MR. MASON: It is set up on a percentage basis.

MR. HOLBURT: Then anything above that is secondary?

MR. MASON: Yes, it is sold as secondary power, and the amount of firm power allocated has nothing to do with the yearly forecast, but is set up in the Boulder Project Act.

CHAIRMAN WORK: In your paper, Mr. Stanley, you touched briefly on a method you folks developed in which you combine precipitation and snow survey data, adding to the precipitation accumulated October to February inclusive, the March increase in snow stored water. Do you expect to continue to make use of that method and to further explore it?

MR. STANLEY: Yes, we expect to continue studying that one as well as all these other things that have been suggested or that we have run across. At present, as I said, that gives us a very good forecast as of April 1, and we hope that the continued use of records will permit that method to continue to be good. We also make a forecast on May 1, of course, and on May 1 we get a good correlation between snow water content and run-off as well as precipitation. I was speaking a while ago of the April 1 forecast.

CHAIRMAN WORK: The reason I asked that question was to tie the Bureau's needs in with a statement I read at the beginning of the meeting from Mr. Stockwell, in which Mr. Stockwell pointed out that he lacked full conviciton as to the value of these earlier snow surveys. I would infer from your remarks that there is a reason that you folks at least are very anxious to have snow surveys as of March 1. I mean that without March 1 and April 1, you wouldn't be able to work out that particular correlation, would you?

MR. STANLEY: No, that is right. We would not be able to.

MR. MARVIN DIAMOND: I have a comment about what you just said, Mr. Work. In the use of snow survey records in stream flow forecasting, we have so few years of record right now that we haven't really investigated the selective use of various forces to find out the best. We have done that with precipitation. We know that in Colorado we get a much better correlation when we use thirteen stations. As the years of records go on in snow survey, we can possibly do the same thing with that, and that, in itself, might be a good reason for not discontinuing any of the courses right now.

CHAIRMAN WORK: I expect you folks appreciate the fact that Mr. Stockwell is perennially in a precarious financial situation. If he

ever broke a string on his little banjo he uses to go around with his Salvation Army Cup, a lot of snow surveys wouldn't be taken, I think.

MR. VERNON RUPP: I have a question to ask Mr. Diamond. If you were working up a standard curve of least mean squares for forecasting precipitation and if you have thirty or forty years of record and you find that the last ten or fifteen years tend to be below your theoretical curve, would you adjust for those later years, or would you recommend giving greater weight to more recent years?

MR. DIAMOND: I would recommend right now, using the entire period. I think one example has been shown by Mr. Stanley in their paper where they selected successive ten year samples. They got correlations ranging from .2 to .9. How can we be sure that the last ten years or the last twelve years won't be followed by another ten or twelve years in which the run-off may be on the high side? I think ten or twelve years is too short a period to base a lot of adjustments on.

CHAIRMAN WORK: Well, we certainly want to thank you gentlemen--Mr. Mason, Mr. Stanley, Mr. Diamond and Mr. Lupton--for some very interesting papers which will be of value to may people, when they are incorporated in the transcript of this meeting. The fact that comments have not been too extensive this morning doesn't mean they are not going to be read with very, very keen interest by many people. We will recess briefly gentlemen, and then come back in about ten minutes and conclude the program.

..Whereupon at 3:30 P. M., a ten-minute recess was taken.

CHAIRMAN WORK: We will come to order, please. The next paper on the program, gentlemen, is one that I suppose we could omit in the interests of conservation of time, since the author is not present, but I am sure that most of us would like to hear that paper as well as read it later when it is published. It is entitled "Water Problems on International Streams" by Charles D. Curran, Engineer, Office of River Control, International Boundary Commission, El Paso. The paper will be read for us by Mr. Stanley.

..Mr. J. W. Stanley then read the paper entitled "Water Problems on International Streams" by Charles D. Curran. See page 73.

CHAIRMAN WORK: We certainly thank Mr. Curran for this paper. Are there any comments? (None)

The next speaker on the program, Forrest Rhodes, Program Director, Cooperative Snow Investigations of the Army Engineer Corps and the Weather Bureau, cooperating, is not here, but we are fortunate in having with us Walter Wilson of the U. S. Weather Bureau, who is the Chief of the Analysis Unit of that project. Walter has consented to give us briefly an outline of the work that is currently being accomplished. A full written account will be in the transcript of this meeting. Mr. Wilson.

..Mr. Walter Wilson then presented the paper entitled "Progress Report from Cooperative Snow Investigations" by Forrest L. Rhodes. (Not available for publication at this time.

CHAIRMAN WORK: That was a very fine resume, Mr. Wilson, of the work you people have under way. Are there questions that any of you would like to ask Mr. Wilsom?

MR. HARRY F. BLANEY: Some of us haven't received his progress report.

CHAIRMAN WORK: How does one go about getting on that mailing list?

MR. WILSON: You may address the request to Forrest L. Rhodes, Program Director, Cooperative Snow Investigations, South Pacific Division, Corps of Engineers, Oakland Army Base, Oakland, California. I won't guarantee that you will all get copies of these reports. There are 500 printed and something like 400 distributed to Operations offices of the Corps, to Engineers, and to the Bureau and other agencies, in a smaller number--agencies participating to a limited extent with the program. We have, I think, something like 50 additional copies that aren't accounted for. If you are members of agencies that already get copies these, you may have to be satisfied with the file copy rather than getting an original copy. We are using public funds for this and want to make the results as useful as we can to everybody who has a legitimate interest in hydrology.

CHAIRMAN WORK: Thank you very much, Walter. Now we come to the concluding phase of the program. The boss called me up last night and said, "I have to catch a plane for Washington, so I would appreciate your leading the discussion for me." So here I am pinch-hitting for George Clyde, Chief, Division of Irrigation.

We want to get your opinions on the present and future value of this Committee, and I think the group should definitely express itself as to the future program that the Committee ought to seek to follow out. Maybe the objectives of the Committee ought to be redefined.

..Chairman work then read a paper on the subject.. Mr. Clyde's outline follows:

MR. CLYDE

PROBLEM:

The Drainage Basin of the Colorado River covers 245,000 square miles in Wyoming, Utah, Colorado, New Mexico, Arizona, Nevada and California. It is estimated that 75 percent of the flow of this river comes from the accumulated snow cover on the higher areas of the water shed. This water in snow storage can be and is measured by means of seasonal snow surveys over the entire watershed before appreciable melting has taken place. Based upon these measurements of water in snow storage and supplemented by meteoroligical and physical data, forecasts os water available at specific points along the stream and for specific seasons can be and are being made.

Because of the vital importance of water to the economy of the west and because of the multiplicity of uses, many agencies, federal, state

and private, are interested in the water supply forecasts. Due to the different uses of water, each of these agencies may make their own interpretation of the measurements of snow cover.

In order to exchange ideas and to develop refinements in forecast procedure and to disseminate information relating to factors affecting the water supply, the Colorado River Forecast Committee was organized.

The objectives of the committee may be stated as follows.

1. To present to interested parties the results of seasonal snow cover measurements on the high watersheds of the Colorado River Basin.

2. To study and discuss the effect of related meteorological and physical factors on the water supply forecasts and the utilization of the water from the Colorado River.

3. To spread useful information and exchange ideas relating to refinements of water supply forecasts and the use of snow cover data.

4. To present statements of potential water supply conditions in each of the states contributing to the flow of the Colorado and the status of holdover storage in reservoirs.

PROGRESS:

1. This is the 5th annual meeting. All meetings except the 4th have been held in Los Angeles.

2. Mimeographed reports have been issued covering each of these meetings. These reports have been made possible through the courtesy and support of the:

(a) Metropolitan Water District
(b) Department of Water & Power, City of Los Angeles
(c) Southern California Edison Company

3. Many interesting and important papers and analyses have been recorded in these reports. There has been considerable demand for copies of them.

FINANCING:

1. No dues
2. No means of financing
3. Have relied on support of friends in Los Angeles for reproducing reports.
4. Mimeographing by SCS

This is not too satisfactory.

FUTURE:

After five years' experience, it is time to take stock of the results:

Is this activity worthwhile?
Should it be continued?
If so, on what basis?
How should it be financed?
When and where should meetings be held?
Should the procedures and presentations be modified?

What is your pleasure?

CHAIRMAN WORK: Well, that explains briefly where we have been. Now, the question is: Where do we go?

Concerning the financing of this Committee, there are no dues. There are no means of financing. We have always relied upon the Committee's good friends in the City of Los Angeles to meet the expenses of transcribing the meetings and making the information available for reproduction. The Soil Conservation Service and the Colorado Agricultural Experiment Station have met the costs from there on out. That was not satisfactory last year when the meeting was held out of Los Angeles. The meeting was held in Reno, I think the three agencies in Los Angeles that had been financing the costs of recording the meetings didn't think it was fair for them to stand the cost of a meeting being held in Reno, Nevada.

Chief Clyde asked some very pointed questions: "1. We have been holding meetings of the Committee for five years. Perhaps we now can form mature judgment of the following points:

"Is this activity worth while? Should it be continued? If so, on what basis? A different type of organization? Rotating the meetings? Meetings more in the center of the basin? Just what should be the future program? How should it be financed? When and where should the meetings be held?"

Chief Clyde wasn't stingy with his questions. He throws the whole thing open for discussion. I think that is a fine idea, and just to start the discussion off, I know Jimmy Jones is all primed with explosive energy and a lot of ideas. Will you start the discussion, Jimmy?

..Mr. James E. Jones then read a paper on the subject under discussion. Mr. Jones's remarks follows:

MR. JONES

The Colorado River Water Forecast Committee meeting is only one of several of similar character, or purpose, and to function should be able to justify its continuance as a separate gathering. For this reason the following remarks are offered for your consideration.

The western forecastman is a large multiple and he has a lot to learn that can best be done by getting together and seeing what the other chap is developing into an improved system. Frankly, the close association of the many men engaged in this work is a thing that yields results not possible of transmission by formal reports.

We feel that there is a specific need for a summation or analysis of the changes that have taken place in the forecasting from snow survey data, and it is desirable to know whether or not improvements have resulted in this activity.

The problem of operating water and power facilities within the minimum and maximum water limits imposed is a far-reaching problem and definitely related to the accuracy of snow survey and forecasting.

The economy measures of the federal government may require the elimination of some of the gauging stations. This can have a very detrimental effect upon long-time studies and is worthy of discussion.

The review of the various forecasts by each of the organizations represented is always of interest.

The situation seems to have reduced to one where it is desirable to hold a general meeting annually where discussion can be held covering forecast procedure methods, field operations and transportation, results of actual forecasts made and the reasons why they varied from actual discharges, and improvements in any line believed to be of benefit to the parties participating.

The disadvantages of the present system are that the gatherings tend to be more local in nature and do not always give the benefit that accrues when more distant people can, or do, attend and inject ideas; the attendance upon a local meeting may preclude the attendance upon the more desirable, but more distant, gathering; the usual corporation is more than willing to permit, in fact encourage, its employees to attend gatherings where work benefits can be said to be obtainable, but seems to believe that where the subject matter has been discussed once that future benefits may be doubtful; corporations naturally desire some return for money invested, either as time of employees or cash, and where they cannot be shown some advantage the tendency is to slow down on granting permission to be absent from regular work.

The restrictions under which the employee of a corporation, either municipal or public service, operates makes it necessary that he show values received for expenses incurred. These values may be either greater cash returns or increased results in service efforts.

The continuance of the Forecast Committee as a general gathering requires the attendance of the corporation employee and it is necessary that he be enabled to demonstrate actual value for each gathering. For these reasons we ask your consideration.

CHAIRMAN WORK: I think we should hear first from the three agencies that have a financial stake in this thing. I think we should hear next from the Edison Company. Is there someone here who can and will speak for the Edison Company.

MR. LANG: I can't speak for the company, but I will speak for myself.

CHAIRMAN WORK: All right.

MR. LANG: I feel rather the same as Jimmy Jones. That is, we have a meeting of the Western Snow Conference held in one place, and a meeting of the Colorado Forecast Committee held some place else, and the A. G. U. in another place--last year the A. G. U. met at Berkeley and the Colorado Forecast Committee met in Reno. This year, we have the Colorado Forecast Committee in Los Angeles, and the A. G. U. meeting in Denver. I do feel that for a great many who have common interests, the whole thing could be thrown into one pot and there could be one meeting. It might be better than to have two or three meetings scattered around the country. That is my personal opinion. I don't put up the money.

CHAIRMAN WORK: I haven't seen Mr. Elder from the Metropolitan Water District.

MR. BLANEY: Mr. Chairman, Mr. C. C. Elder called me before leaving for Washington and said he was sorry that he couldn't attnd the meeting, but that the Metropolitan Water District had a continued interest in this meeting and program, and they would abide by whatever decision was made by those present, particularly representatives of the Southern California Edison Company and the City of Los Angeles. I think Mr. Elder probably has about the same sentiments that Mr. Lang and Mr. Jones have expressed here today.

In that connection, I might also state that Mike Dowd of the Imperial Irrigation District was unable to attend the meeting. As perhaps you know, he and Raymond Mathew, of the Colorado River Board of California, and Harold Conkling, Consulting Engineer for the Board, are in Washington attending hearings in the controversy between Arizona and California.

While I am on my feet I would like to express my appreciation of the fine cooperation given by Mr. Lang, Mr. Jones, and Mr. Elder, and also Mr. George Gleason of the State Engineers' Office who furnished this meeting place and has provided a meeting place for previous meeting in Los Angeles.

CHAIRMAN WORK: Another principal agency on the receiving end of all this forecasting is the Bureau of Reclamation. There are several representatives here. I wonder if you would care to speak for the Bureau, Mr. Stanley?

MR. STANLEY: You don't want to hear from the Department of Water and Power?

CHAIRMAN WORK: Yes, but I would like to hear from you right now.

MR. STANLEY: I think it has been amply demonstrated here today that the problem of forecasting Colorado River flow is far from its ultimate solution. The continued exchange of ideas and the examination of all our methods is going to be very valuable. The question as to where that should be done, whether in the Colorado Forecast Committee meeing or in connection with the Western Snow Conference, is one we hadn't considered especially. We had thought the Colorado River Water Forecast Committee was important enough and was accomplishing enough that we would like to see these meetings, as such, continued. Of course, we don't help pay the bill. I am not in a position to put up any money to that effect.

MR. GEORGE LEWIS: I should like to give my opinion as an individual, as one who has been on this Committee since its inception. By the way, Mr. Clyde overlooked one primary objective of this Committee. He inferred as much, but frankly, the purpose of it was to reduce the error of the Colorado River Forecast. At the time it was conceived, it was not uncommon to have errors as much as 40 per cent in the run-off of the Colorado River, and it was thought at that time that the pooling of the knowledge and experience of the different forecasters might result, or it was hoped it would result, in a reduction of that error. It has undoubtedly reduced the error, and in other channels, it has improved the procedure. It has caused some considerable interest and investigation into the methods of forecasting the run-off, and as to wehther or not it should be continued, I believe that should be measured by what is has accomplished. In that regard, the accomplishments are better known to those who use our data and who benefit by it. Those are the Power Companies and the Metropolitan Water District and those who pay for it. So it is largely up to them to determine whether or not what has been accomplished is worth the price.

There is another angle, too, as to whether the Department of Reclamation, operating the Hoover Dam, would welcome further help from the Colorado River Water Forecast Committee. Those points should be considered before we reach any definite conclusion as to whether it is worth continuing, or not.

CHAIRMAN WORK: Is there someone else who would wish to speak for the Bureau of Water and Power? Mr. Mason?

MR. MASON: I contacted Mr. Garman, the Chief Electrical Engineer. on this subject, and told him I might be called upon to comment on it. He seemed quite favorable for the continuation of the work. The possibility of its being carried on in some other way we did not discuss, but he felt that because of the personal contacts and the interchange of ideas, as well as any increase in the accuracy of the forecast, that the organization should be carried on.

CHAIRMAN WORK: There doesn't seem to be much question, then, gentlemen, as to the desirability of the objectives of this Committee being continued in one way or another. If I understand you correctly, Mr. Jones, Mr. Lang, Mr. Lewis, Mr. Stanley, and Mr. Mason, you all seem to state definitely that this Committee is performing a worthwhile task, is filling a need. To settle that conclusively, I would like to ask if

there is anyone in the room who feels that the Committee is not performing a useful function? (None)

All right, it seems unanimously demonstrated that the Committee is desired, that the Committee is functioning, that the Committee is producing to some extent at least, what is needed.

Now, the question becomes: How can the Committee orient its organization and its possible affiliation with other forecast committees or with other groups to get the same results or better results, and yet meet the objections that these gentlemen have raised that too many meetings are being held each year.

Now, Mr. Jones suggested that this meeting be combined with the meetings of other forecast committees, with the annual meeting of the Snow Conference, and possibly with some section of the A. G. U., all into one bang-up annual meeting. I will call on Mr. Houston of the Soil Conservation Service who has had some experience with forecast committees to give us his slant on that.

MR. HOUSTON: Sometimes I doubt whether the Columbia Basin people would be interested in moving out of their area to join with another group. That is my personal opinion. They have been going for about 11 or 12 years, and it has been quite a satisfactory arrangement. I agree with these other gentlemen that we could combine some of these meetings and benefit by attendance at such things as the Western Snow Conference and the A. G. U., which we may have to miss now. As to how it should be done, I don't know.

CHAIRMAN WORK: What do you think about that, John?

MR. STANLEY: Somehow, I think a meeting of the Water Forecast Committee by itself is important. Perhaps we could adjust our program in this way: that we aim mostly toward exchanging of ideas and examination of each other's methods and learning all about them that we can. The papers that are presented at the Western Snow Conference and the A. G. U. on snow forecasting have a lot of value and are technical, but it is a little different from what I thought we are supposed to be trying to get out of these meetings--that is, the actual getting together on the problems we have and helping each other to solve the problems. Do you see what I am shooting at there?

CHAIRMAN WORK: Yes. What do you think, Mr. Rupp?

MR. RUPP: It seems to me the question that Mr. Jones raised is rather valid, even from the standpoint of Federal Agencies. It is difficult to justify transport to various different meetings, and if we could consolidate them and retain these meritorious parts of it in a side meeting, as Mr. Jones suggested, I would feel that it would definitely be a good move. It would not only distribute to others the things we gain, but also let more of us participate in a single meeting and obtain the benefit of the things that are presented at those meetings.

CHAIRMAN WORK: How do you feel about this, George?

MR. GEORGE LEWIS: I can see the benefit of combining this meeting with the A. G. U. or with the Western Snow Conference, because as Mr. Rupp just explained, many of the problems that we may solve would be equally interesting to all those people, and we could divulge a good deal more information at a single meeting than we could at this one. However, it would require considerable investigation or arrangement to line it up. I might make a suggestion that you appoint a committee to follow up the opinion as expressed here, contact either the A. G. U or Western Snow Conference and make the arrangements, if that is the concensus of opinion. Personally, I think it is a good idea, but, in any event, I still claim that the criterion to go by is the wish of the people that pay for the publication and pay our wages while we are here. Their voice should over-ride ours.

CHAIRMAN WORK: The sentiment, as I have it from the Bureau of Power and Light, the Edison Company and the Bureau of Reclamation, and from what Mr. Blaney said of the attitude of the Metropolitan Water District, is that those agencies want the forecast meetings continued and they want forecasting procedures broadened and improved. Also they would like to have their employees given an opportunity, however, to perhaps make one trip to one meeting a year to get all that information.

If it meets with the approval of the group, I will appoint a committee of three members to get together with the Western Snow Conference for the purpose of sounding out the conference to determing if the Western Snow Conference will welcome the attachment of the Colorado River Water Forecast Committee to the Western Snow Conference in the future as a section, so to speak, which would be entitled to have its own separate meeting for consideration of its own particular problems, and also, then, to share in the deliberations of the entire conference; and with the further thought that this Committee of three will sound out the Western Snow Conference on the Western Snow Conference's paying the bill. Of course, the Western Snow Conference must then approach the Edison Company and the Bureau of Water and Power, and the Metropolitan Water District as contributing subscribers to the Western Snow Conference. It might just possibly mean a slight increase in the contributing subscribers to the Western Snow Conference. It might just possibly mean a slight increase in the contribution for which they would be solicited for. Now, let's have a little discussion on that.

MR. WALTER WILSON: I think that everybody would get more for his money by being able to attend all these meetings without having to travel to more than one. I was just up at Portland earlier this week. I think my case is typical. I just happened to be there for the other conferences, and stayed over an extra day and participated in part in the Columbia Committee. I wouldn't have come here, except for the fact that Mr. Rhodes was unable to come, and it seemed important for our program to be represented by one person. Only one member of our group is going to Denver. I happen to be that person. By an odd coincidence I happen to be going to these meetings, but it would have been better if I could have gone to only one.

It is not, perhaps, entirely coincidence that the very things you have been talking about are also under consideration by the A. G. U.

An advisory group has been appointed in the west here to consider a more formal regionalization of the A. G. U., itself. I suggest that if it is the judgment of this group that the A. G. U. should be considered in addition to the Western Snow Conference, that collaboration be had with this group, the chairman of which is Dr. Veihmeyer. Mr. Jones has already described a meeting which would be in some central place, with part of the meeting divided into small groups discussing such problems as Colorado, Columbia, California, and other regional problems. All of us would benefit from that more than we could from a single meeting such as this, and there would be general problems of interest to all of us. Perhaps some of the papers presented at this composite meeting would be published by the A. G. U.; perhaps some by the Snow Surveyor's Form. It is entirely possible that all the papers would be accommodated by those two publications.

MR. BLANEY: Mr. Chairman, I am sorry that Mr. Stockwell isn't here, because some of the things you have discussed right now he has attempted to do with Mr. Parshall. I am a member of the Executive Committee of the South Pacific Section of the A. G. U., and we took up with Dr. Veihmeer the matter of combining this meeting with the A. G. U. meeting, which was held at U. C. L. A. in February.

As I understand it, most of the University people can't come any time except during their vacation period, which occurs in February, and that was too early for our meeting here. Mr. Parshall and Mr. Stockwell from my correspondence with them, attempted to combine this meeting with the Snow Survey and the A. G. U. meeting at Denver. Now, I don't know just what the difficulty was there, but apparently it wasn't successful. If you are considering a meeting for next year, and are considering holding it in Los Angeles, I would like to call your attention to the fact that the American Society of Engineers are going to have their spring meeting in Los Angeles. They haven't had one here for seven years. They are holding it this year in Oklahoma City. In April in Los Angeles, the Irrigation Section of the Society are going to consider, probably, the problems of the Colorado River. Also, the Hydraulics Section, which Mr. Barr is acting on, will probably give papers on sedimentation in reservoirs. That is usually held about the middle of April.

CHAIRMAN WORK: Let me give you just a little history, then, on the efforts that have religiously been made to coordinate the activities of this Committee to those of the Snow Conference and the A. G. U.

We tried last year to arrange a three-way meeting between the Colorado River Forecast Committee, the Snow Conference, and the A. G. U, and the A. G. U. dates were rather inflexible. As Harry pointed out, it was a February meeting. I won't say the meeting date of this Committee is fixed hard and fast, but after all, we are dealing with a timely subject: "What is the flow of the Colorado River going to be?", so we don't have much latitude as to date of meeting.

We don't know what it is going to be in February, and certainly, a year from February is much too late. In other words, this meeting is being held now within probably a very few days either one way or the

other of when it ought to be held, because we are grinding through our grist here of timely current data, and the stuff has to be timely or it is of no value.

So, there are two things that are almost irreconcilable: The A. G. U. winter meeting schedule, and the Colorado Forecast Committee mid-April meeting schedule.

Now, we did reconcile that as far as the Western Snow Conference is concerned. The Snow Conference met last year the middle of April. They are meeting this year toward the latter part of April, and April meetings work out all right for the Snow Conference. Then, there is another thing, too. The A. G. U. apparently is taking the attitude that the Snow Conference is coming of age. The mature counsel that the Snow Conference received for many years from the A. G. U., the financial support it received, and the old brotherly lift on the elbow that it received, have not been noticeable in recent years. The Snow Conference, frankly, is more or less on its own. It has been compelled to finance the publication of its own transactions.

Now, I don't say that is good, and I don't say it is bad. It is just something that happened. The Snow Conference is going to have a whale of a good meeting in Denver. They are going to finance their own publication. The Western Snow Conference is going to be able to make its own way. It is doing it now, and I don't know, Walter, about the idea of getting this all too complicated right now. I think if we try to work out a tie-up with the Western Snow Conference and simultaneously tie-up with the A. G. U., we will run into too much confusion, I would rather see us just tied up with the Western Snow Conference, if they want us, and work out the A. G. U. idea later, perhaps, if other things seem propitious. But you know the background on that as well as I do, Walter. I really don't think we ought to consider that at this moment.

Is there any further discussion on this particular point?

MR. RUPP: Even if, as Mr. Lewis suggested, a Committee is appointed to investigate this combination, or if it is done through some other means, would there be any harm, though, in contacting the A. G. U. to see what they could do? It wouldn't necessarily commit anybody, but just bring it to their attention.

CHAIRMAN WORK: No, there would be no harm done. The question might become: "Who should contact them for what?"

MR. RUPP: I am assuming you would have either a committee formed or someone in the permanent committee would make the arrangements for the combination of whoever they would combine with. In other words, somebody will be appointed to have it upon himself.

CHAIRMAN WORK: I think the duties of this committee ought to be pretty well defined for them. The Committee should have all the latitude in the world in carrying out the arrangements that they are to make within the general sphere of what they are told to accomplish, but I am not

in favor of getting this thing all spread out wide right now, Walter. I would rather investigate a concrete suggestion that has been made here today, that we affiliate with the Western Snow Conference and get them to finance these little transactions here, which can stand on their own feet as transactions of the Colorado Forecast Committee, and then go into this other affiliation with the A. G. U., later.

But here is the thing I have been a little afraid about in these meetings, something I had hoped would come about in the Forecast Committee today, and that didn't come about, and that is a rather detailed study of "How come this estimate, and how come that one?" (Referring to estimates on blackboard) It seems to me that is the purpose of this Forecast Committee to really get in and get on the mat and say: "Why is this forecast high? Why is this forecast low?" Perhaps the authors of these forecasts could gain information from someone else in this meeting that would conclusively indicate to them that they ought to come up a little or come down a little, and thereby produce a more reliable forecast figure that these operating agencies can use. But we didn't get into that at all today. We had some mighty fine papers on the long range aspects and long range ambitions, but we didn't get down to that little trifling detail of: How come the difference between 8,600,000 and 12,000,000. I may be wrong, but I always thought that should be the job of this Committee.

MR. GEORGE LEWIS: I agree with you, and I made a suggestion--this will be the third time--that we should go back and look over what we have done and evaluate it and make a study of the different forecasts all the way back for the five years and see what system or what method produced the usable forecast within the limits of accepted error, so that sooner or later we can begin to point toward that system or formula which will give us the best forecast. As I say, I suggested that two or three times before, but apparently, no one has the incentive to do it. But sooner or later we will have to cast up the account and see what we have accomplished. We come here and one makes an estimate of 12,000,000 and another 8,600,000. There is quite a differential. Certainly there is a reason in the preparation of their forecasts for that difference, and, as you explained, it can't be made in any one forecast meeting, but if at our meeting next year a study can be made of all previous forecasts and where the error occurs and why, we would certainly learn something from it.

CHAIRMAN WORK: Do you think, George, that we ought to work that out, or some variation of that, as a definite part of next year's program?

MR. LEWIS: That will give you a guidepost by which to proceed. At least, it is a matter of lining up what is to come in the future, and that is one of the questions that is to be decided here.

MR. STANLEY: I agree with both of you, Mr. Lewis and Mr. Work, and something like that was what I was getting at a while ago when I spoke of the difference between the purpose of our meeting and the Western Snow Conference. The Western Snow Conference should be more formal and have papers of a formal nature prepared. Here, our purpose is a little

bit different, and it seemed to me our program, in some phases today is a little more formal. This job you mentioned is the one we have to do here and should do.

MR. LANG: I want to clear up a point some of you may be laboring under. We are not talking for the abolition of the Committee. We are just talking about consolidating the meetings.

CHAIRMAN WORK: I think we understand that clearly. I don't think anybody had any other impression at all.

Perhaps it would be best if we had a motion that a Committee of three men--or five men, or whatever you think best--be appointed by the Chairman to work with the Western Snow Conference in an effort to work out an amalgamation of some sort. If we had such a motion before the house, we could put that to a vote.

MR. LEWIS: I will make the motion.

CHAIRMAN WORK: Phrase it, will you, George?

MR. LEWIS: It should read as you gave it there: That a Committee-the members of which I think should be allotted by the Chairman--I am not going to indicate how many--of the members be appointed to investigate the possibility of combining the Colorado River Forecast Committee meetings with the Western Snow Survey Conference, and to carry out such measures as are necessary to complete the arrangements in time for the meeting next year.

We had just as well authorize the Committee to go ahead and make the arrangements instead of having to report back. What do you think? If they are cognizant of our desires and know the wishes of the members, they can go right ahead and complete the negotiations.

CHAIRMAN WORK: I think so, George.

MR. LEWIS: Otherwise, they report back and forth and next year we would have to listen to the Committee's report instead of attending the Conference.

CHAIRMAN WORK: Is there a second to the motion?

MR. RUPP. Would there be any need to state a time limit within which this Committee is to make arrangements to combine?

MR. LEWIS: In time for next year.

MR. RUPP: We are assuming now, of course, that the Snow Conference is held at a time that would fit the needs of this Committee.

CHAIRMAN WORK: We are assuming that this Committee might be able to induce the Snow Conference to hold their meetings at a suitable time.

MR. RUPP: That is not specifically in the motion.

MR. LEWIS: No, but the Committee will be empowered to select the date if it suits them. It may be possible that they can make no arrangements, in which case they will so report. But let us empower them to make all arrangements within their own judgment. They know what the members want. They know what the motion is. Let's give them the power to go ahead and complete the deal to the best of their judgment.

CHAIRMAN WORK: Is there a second?

MR. HARLOWE STAFFORD: I second the motion.

CHAIRMAN WORK: All those in favor, say "Aye"; opposed, "No."

..Motion voted; Motion carried...

CHAIRMAN WORK: The motion is carried, and this will be referred to Mr. Stockwell for his appointment of a Committee of suitable size and character to carry out the wishes of the Colorado River Water Forecast Committee in this matter.

Now, the hour is getting late, gentlemen. Is there anything to come before the Committee before we adjourn? If there is no further business, I declare this meeting adjourned.

..Thereupon the meeting adjourned at 5:30 P. M...

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FLOW OF THE COLORADO RIVER DURING THE 1948 SEASON

by

John H. Gardiner, District Engineer
U. S. Geological Survey, Tucson, Arizona

For the purposes of this paper normal runoff is the median runoff for the 25-year period 1921-45 inclusive.

The runoff during the 1948 water year at Grand Canyon was 103 percent of normal, or normal for all practical purposes. However, inspection of the monthly variations for the water year discloses the fact that October, the first month of the year, was 185 percent of normal with the monthly percentage steadily declining, crossing the normal line between June and July and ending the water year with September at almost a record low or only about 48 percent of normal.

The 1948 water year runoff was 13,870,000 acre-feet compared with a normal of 13,400,000 acre-feet. Of the total runoff, the Colorado River above the Green contributed 6,514,000 acre-feet or 109 percent of normal. The Green River contributed 4,146,000 acre-feet which is 96 percent of normal, the San Juan contributed 2,306,000 acre-feet, which is 110 percent of normal. The Little Colorado River contributed 182,200 acre-feet, which is 105 percent.

In contrast to the 1948 water year, 1949 started out with the monthly flow definitely below normal with October being 70 percent of normal but increasing each month until normal flow was reached in February, March being 123 percent. For this reason the first six months of this water year give a poor comparison with the same period of 1948 since it shows a flow only about 75 percent of last year. For the first six months of this water year the Colorado River at Grand Canyon produced 2,664,000 acre-feet, 97 percent of normal. Runoff was quite low in the northern part of the basin with the Green River 81 percent of normal, and increasing toward the southern part with the San Juan River 118 percent and the Little Colorado River 245 percent of normal. The same trend is evident for March with the San Juan and Little Colorado Rivers producing the largest percentages of normal runoff, 148 and 252 percent respectively. If this trend continues prospects are good that runoff this year will be better than last year.

For those interested in a more detailed analysis, the records are tabulated below and will be available through your chairman.

COLORADO RIVER BASIN
Runoff in acre-feet

	Oct.1, 1947 to Mar.31,1948	% of normal	Oct.1, 1948 to Mar.31,1949	% of normal	Water Year 1948	% of normal	March 1949	% of normal
COLORADO R. ABOVE GREEN R. (CISCO, UTAH)	1,473,000	141	1,129,000	108	6,514,000	109	220,300	112
Colo. R. at Glenwood Springs, Colo.	*364,050	114	298,800	93	1,939,000	92	57,670	99
Roaring Fork at Glenwood Springs, Colo.	199,400	118	159,300	95	1,078,000	110	24,920	106
Gunnison R. near Grand Junction, Colo.	479,000	127	341,400	94	2,495,000	122	65,280	97
GREEN RIVER AT GREEN RIVER, UTAH	1,103,000	116	766,600	81	4,146,000	96	276,100	115
Green R. near Linwood, Utah	369,600	161	212,000	92	1,447,000	110	69,400	104
SAN JUAN R. NEAR BLUFF, UTAH	569,900	148	452,500	118	2,306,000	110	152,600	148
San Juan R. at Farmington, N. Mex.	418,900	135	335,300	108	2,133,000	112	134,100	148
COLORADO R. AT LEES FERRY, ARIZ.	3,378,000	132	2,487,000	98	13,670,000	104	704,700	121
LITTLE COLORADO R. AT GRAND FALLS, ARIZ.	90,020	176	125,000	245	182,200	105	86,620	252
Little Colo. R. at Cameron, Ariz.	106,000				201,100			
COLORADO RIVER AT GRAND CANYON, ARIZ.	3,547,000	129	2,664,000	97	13,870,000	103	795,400	123
VIRGIN RIVER AT LITTLEFIELD, ARIZ.	66,600	79	70,910	84	116,400	68	17,870	112

*Adjusted for 97,260 acre-feet, release from Green Mountain Reservoir.

SNOW SURVEY PROGRAM ON UPPER COLORADO RIVER BASIN

by

Homer J. Stockwell, Associate Irrigation Engineer,
Division of Irrigation, Soil Conservation Service,
Fort Collins, Colorado

At the present time, there are a total of 115 active snow courses on the Colorado River Basin. This includes some courses on the divides or in areas immediately adjacent to the basin. By states, Colorado has 56 courses; Wyoming 7 and Arizona and western New Mexico 23 and Utah 29.

In Colorado, snow surveys are made on nearly all courses on the first of February, March, April and May. In Wyoming, on the Green River, February 1 surveys are omitted. In Utah only April 1 snow surveys are made. This year, however, the measurement schedule in Utah has been expanded to include March 1 and possibly May 1. Arizona snow surveys are scheduled beginning January 1 and ending April 1 with mid-month surveys. Currently the results of the first of the month surveys are published in the Colorado River Basin report and mid-month surveys are published in the Arizona report.

In obtaining these surveys in Colorado, Wyoming and New Mexico it is necessary for 26 forest or park rangers and 47 other persons to travel over 2,800 miles on foot during the season in addition to automobile travel. There distances range from 3 to 18 miles from the end of the road. A few courses are along highways which are kept open throughout the year. Foot travel is not the only problem as it is worse than walking at times to negotiate an ordinary automobile over roads with occasional drifts or where there is no bottom to the mud in late season.

During the past season I have raised considerable objection to extensive snow surveys on February 1. The major reason for this is that February 1 is so early in the snow accumulation season that the results are almost as likely to be misleading as indicative of the flow to come. Of course, we realize that, but the public, who are anxious about the prospective water supply, are likely to remember early season data and not follow it out through the remainder of the snow season. This is especially true if early indications are for good flow.

During the past few years it is becoming increasingly difficult to find people who will make surveys in remote areas. This may change with general economic conditions. However, as long as people have jobs or a little money they are reluctant to do the extreme hard work and take the risk involved in making a long snow survey hike. It may be difficult to believe but some have stated that they do not have proper clothing to use on these trips and of course the outlay for such clothing would take more than the pay for the services.

I believe that the snow survey schedules should be revised to include only a few easily accessible courses for February 1 measurements, all but the most inaccessible ones for March 1, and all courses should be measured April 1. We need a number of additional courses to be measured during the latter part of the season to fill in the gaps. This is particularly true on some parts of the Yampa, Gunnison and San Juan Rivers. These areas are generally too inaccessible for foot travel. We should also give consideration to the abandonment of snow courses which are proving to be of little value for forecasting purposes.

In regard to mechanized snow surveys on the Colorado River, there has been very little use of this equipment. We have rented two Tucker Sno-Cats and are using an Army M-7 belonging to the Public Service Company of Colorado. We could use more of this equipment to reach back areas and to improve the quality of the snow survey measurements.

Courses recently established are Monarch Lake, Granby and Grand Lake on the Upper Colorado for use in connection with the Colorado-Big Thompson Project. Monarch Lake may eventually replace Thunderbolt Peak, because of its inaccessibility and apparent lack of forecast value. Glen-Mar snow course on the Williams Fork may replace Middle Fork Camp Ground. Kannah Creek course was established at the request of the City of Grand Junction on its municipal water supply watershed. This year two new courses have been established on the Continental Divide at Cochetopa Pass and Spring Creek Pass which should fill quite a gap on the Gunnison River, as well as the Rio Grande River watershed. A new course, Lake City, was established to replace Sunshine Mountain because of the hazardous route to the course. Trout Lake snow course may eventually replace Lizzard Head Pass if the narrow gauge railway is abandoned. Marshall Pass and Poncha Creek may meet the same fate if the railroad is discontinued over this pass. However, we have several years' records on Porphyry Creek and Monarch Pass nearby.

Next year we hope to have some new courses on the headwaters of the Piedra, Pine, Animas and other tributaries to the San Juan. In the past this area has been largely unexplored.

REPORT OF SNOW-WATERSHED CONDITIONS
of the
UPPER COLORADO RIVER BASIN IN UTAH

by

Don Mitchell, Irrigation Engineer
Division of Irrigation, Soil Conservation Service
Logan, Utah

The Forecast Bulletin for the Upper Colorado River Basin in Utah has been delayed somewhat this year due to the heavy snow storms in this area during the first week of April as well as the extremely heavy accumulation of snow from this past winter.

This season in the Colorado River Basin in Utah we had the deepest snow cover and highest water content ever recorded for many of the stations in the high Uintahs.

Ordinarily the snow surveyors have to travel about 25 to 35 miles on foot one way to reach snow courses in the high Uintahs, this year due to the deep snow and prolonged winter they had to travel as much as 50 miles on foot to reach snow courses. This caused some delay in securing measurements.

The water supply outlook is exceptionally good in all areas of the Upper Colorado River Basin in Utah. There is every possibility of damaging high water from many of the tributaries to the Green and Colorado Rivers in the Uinta Basin area. In the LaSal and Monticello districts there has never been such a high water content measured in the snow before. However, the streams are small and possibility of damage from high waters is not likely. The abundant snow cover however should forecast a good supply of forage for stock in this area.

In the Virgin Drainage to the Colorado there has been an extremely heavy accumulation of snow these past few months. Most of the snow is still there with potential high water in existance if the right climatalogical combination comes about.

WATER SUPPLY OUTLOOK IN ARIZONA AND NEVADA

by Clyde E. Houston, Irrigation Engineer
Division of Irrigation, Soil Conservation Service
Nevada Experiment Station, Reno, Nevada

ARIZONA

The past six years of continuous drouth in Arizona came to an end during the past snow season. Generally, the outlook for water in the irrigated areas of the state for the 1949 season is very good. As of April 1 the water held in the eight important reservoirs was 30% of capacity, or three times the amount of water stored on April 1, 1948. The San Carlos Reservoir, which last year was practically empty, now contains about 25% of capacity.

The extremely heavy snow storms of January and February combined with low temperatures retained a record snow pack upon the higher elevations throughout the winter. The water content of the snow remaining on the principal water sheds is over 200% of normal. This would indicate that with normal precipitation continued good runoff will result.

NEVADA

Snow cover on areas contributing to Colorado River in Nevada was extremely high this year. On the Spring Mountains near Las Vegas snow stored water contributing to the Las Vegas Artesian Basin was 80 percent better than a year ago and 60 percent greater than the eight year average. Snow courses in the Virgin Mountains, established this year in cooperation with the towns of Bunkerville and Mesquite, showed heavy early snow, but with practically the entire cover gone at this time. Indications are that the two towns will not have to start hauling municipal water until late July or August. Snow courses established in Pine and Mathew Canyons tributary to Meadow Valley Wash were measured this year for the first time in cooperation with the Union Pacific Railroad. February surveys showed a potential flood hazard in the snow pack as surveyed at that time. March surveys indicated a decreasing hazard which could probably be realized only by heavy warm rains falling on the snow pack. April surveys indicated that any danger of high waters from snow melt no longer exists.

SNOW COVER CONDITIONS IN WYOMING

by

L. C. Bishop, State Engineer
Cheyenne, Wyoming

According to the Federal State Cooperative Snow Surveys, the snow cover of Wyoming as of April 1, 1949, is above the average on all courses reported. Range conditions for livestock and wild game animals is favorable for those that have survived the most severe winter of record in this State.

BIG HORN RIVER

The snow cover on the Upper Wind and Pope Agie River watersheds is well above the average of the last thirteen years. On the Shoshone watershed, the snow water content is 150 percent of normal and well above a year ago. Similar conditions exist on the headwaters of the Greybull River.

On the east slope of the Lower Big Horn River Basin the snow cover is about 25 percent above normal. The runoff for the entire Big Horn Basin is expected to be substantially more than the past twelve year average. Soil moisture conditions are very good along the Big Horn River both above and below Wind River Canyon.

Snow cover on Powder and Tongue River tributaries is normal or slightly below.

CHEYENNE RIVER AND BELLE FOURCHE RIVER

Snow cover in the Black Hills is about 100 percent above normal, and the prospects are good for irrigation water supply in this area.

NORTH PLATTE RIVER

Snow cover on the headwaters of the Laramie and Sweetwater Rivers is well above normal. Outlook for irrigation water supply for 1949 season is excellent. We are looking forward to the filling of all the reservoirs presently constructed on the North Platte River for the 1949 season.

GREEN RIVER

The snow water content on the Green River watershed in Wyoming is 118 percent of normal, and well above the twelve year average. The outlook here is good for the irrigation water supply for the 1949 season.

SNOW COVER CONDITIONS
on the

COLORADO RIVER AND ITS TRIBUTARIES IN COLORADO
by Homer J. Stockwell

Colorado River (above Grand Junction): The snow cover on the Colorado River above Grand Junction is 18 percent above normal and slightly over a year ago. The distribution of snow on the watershed indicates that normal snow cover exists on the Blue, Frazer and Eagle Rivers and somewhat above normal on other tributaries in Colorado. The April-September flow of the Colorado River at Glenwood Springs is expected to be 1,600,000 acre-feet and for the Roaring Fork 950,000. March precipitation along this stream was generally deficient but soil moisture conditions are good.

Gunnison River: On the Gunnison River drainage the snow cover is slightly heavier than on the Colorado River. Seasonal precipitation in valley areas has been well above normal and soil moisture conditions are excellent. Snow cover is relatively heavier on the southern tributaries. The flow of the Uncompahgre is expected to be over fifty percent above normal. For the Gunnison River at Grand Junction the April-September, 1949 flow is expected to be 1,800,000 acre-feet. Storage at Taylor Park reservoir is now 65,000 acre-feet as compared to 87,000 on April 1, 1948.

Yampa and White Rivers: On both of these streams the April 1 snow accumulation is very high, 35 percent above normal. The summer flow of these streams will be as great as any in the past 12 years. The flow of the Yampa River will probably exceed any recent summer flow and if temperatures are above normal at melting time unusually high peak flow may be expected and some damage will result. Similar snow conditions exist on the headwaters of the Little Snake River as on the Yampa. Seasonal precipitation in valley areas has been much above normal and soil moisture conditions are reported as good.

San Juan and Animas Rivers: Snow water contents measured on the headwaters of these streams was over 50 percent above normal April 1. Total summer runoff will be high but unless April snow accumulation is above normal the peak flow will not exceed that for the year 1941. Estimated April-September flows for the San Juan at Rosa, New Mexico is 950,000 acre-feet, and for the Animas at Durango 750,000; Vallecito reservoir is down to 33,000 acre-feet from 57,000 on February 1. The flow of the Los Pinos below the reservoir for the summer period should be about 350,000 acre-feet. Soil moisture conditions throughout southwestern Colorado are described as excellent.

Dolores River: On the headwaters of the Dolores and San Miguel Rivers the snow-water contents are also unusually high. For the Dolores River the total April to September flow is expected to exceed any year since 1936 when snow surveys were started. Based on current data there is a four out of five chance that the peak flow of the Dolores at Dolores will exceed the year 1941.

WATER SUPPLY OUTLOOK IN CALIFORNIA

by Fred Paget, Engineer

Division of Water Resources
State of California
Sacramento, California

California has had a good snow year this winter and north of the Tehachapis there will be ample water for irrigation, power and industry.

South of the Tehachapis the precipitation and runoff have been below normal, especially the runoff. Therefore gravity diversions will be much smaller than normal, requiring more water to be pumped from underground basins. Most of the basins have sufficient capacity to take care of the situation but difficulties may be encountered in the more shallow basins.

The year started off well with a snowpack some 5 feet deep at the high elevations of the Sierra before the middle of December. Storms bringing additional snow continued off and on all winter long.

The weather this year was exceptional in that it was so cold. Along with the stalling of trains in the Rockies and Operation Haylift in Nevada, California also experienced very cold weather - the coldest long stretch of winter weather in decades. During January at Beiber in Northern California there were only 5 days during the month when temperatures did not go below zero. One night it got down to 28 below. In Southern California at Big Bear Lake temperatures as low as 17 degrees below zero were recorded. Snow fell in Los Angeles.

Comparatively low temperatures prevailed during the storms and as a result there was more snow low down in the Sierra foothills than for many years. To many people this suggested the threat of floods and they had to be assured that while in California a good rain can bring a flood at any time during the winter if it rains hard enough and long enough, a good snowpack is on the whole a safeguard against flood. The snow that might be melted by a warm rain at low elevations is more than offset by the rain absorbing and runoff retarding effects of the deep pack over the high country.

The low snowpack also fell on foothills where the soil moisture depletion of the summer before had not been replaced so that a considerable portion of the water in the low snow would go to satisfy this soil moisture deficient before there would be much contribution to runoff.

At high elevations the snowpack this year at no time got up to normal. On April 1st the high snowpack ranged from 75% to 90% of normal.

Because of the preponderance of low snow, 300% above normal at some low stations, and the below normal pack at high elevations, forecasting of runoff has been a little difficult this year and may not be as accurate as usual, but time will tell.

The bulletin put out by the Division of Water Resources predicts the spring runoff from melting snow to be 93% of normal in the Sacramento Valley, 90% of normal in the San Joaquin Valley and 77% of normal for the streams tributary to Tulare Lake. Since this is more water than the irrigation districts of the Kings and Kaweah normally use, it is probable that some water will this year have to be discharged into the Tulare Lake Basin area.

April so far has been dry, if it keeps on with no rain the rest of the month it will be necessary to cut back these forecasts of runoff a little when the May bulletin comes out next month. But in all events it seems assured that the areas of California depending on the snowpack will have a good year this year.

FORECAST OF FLOW OF COLORADO RIVER
NEAR GRAND CANYON, April-July 1949

by Tucson District, U. S. Geological Survey
Presented by John H. Gardiner, District Engineer

A great deal of work was done this year in an attempt to find ways of improving the forecast and to identify those factors which make high accuracy hard to attain. The conclusion is that there is an irreducible minimum error caused by the large effect of the unknown precipitation from April to July. By the methods described below, runoff for April to July was computed for each year 1931-48, both with and without the precipitation from April to July as a factor. When the presipitation was not included as a factor the coefficient of correlation was 0.862, indicating an unexplained variance of a little less than 26 percent. When the precipitation for April to July was included the coefficient of correlation was 0.963 indicating an unexplained variance of a little more than 7 percent. Thus, most of the unexplained variance, that is, about three-quarters of it, is caused by the unknown precipitation April to July. Improvement in the accuracy of the forecast will, at best, be relatively small, in view of this fact. Of the factors which should be investigated further, the influence of the ground-water level is believed to be of considerable importance. At present, records of ground-water levels are too short and incomplete to be of any real use. One of the most promising approaches to an increase in the accuracy of the forecast in future years probably lies in the increase in available ground-water data, and other independent factors.

The forecast for this year was made by dividing the basin above Grand Canyon into four sub-basins--Colorado River above Cisco, Green River above Green River, Utah, San Juan River above Bluff, and the intervening basin downstream from these three basins and above Grand Canyon. Each of the four sub-basins was studied individually to determine the relations between runoff and water content of snow on April 1, antecedent runoff from October to March, and degree days of maximum temperature above 40 degrees for January to March. Equations involving these three factors were computed for each of the four sub-basins.

The period for which the study was made was 1931-48. Basic data are available for all factors for that period, except that no snow courses were measured prior to 1936 in Wyoming and Colorado. This deficiency was remedied by extending the snow-course records back from 1936 to 1931 by means of correlations of snowcourse measurements with precipitation records, precipitation was not taken as one of the factors entering into the equations for computation of runoff.

Runoff for each year was computed for each sub-basin by means of the equation for that sub-basin. A new equation was then set up to find the relation of the actual flow at Grand Canyon with the computed figures of flow for the four sub-basins, and the forecast for Grand Canyon was made from this equation.

Assuming normal precipitation during the next four months our forecast for Grand Canyon for April to July 1949 is 11,300,000 acre-feet with a standard error of 1,400,000 acre-feet.

FORECAST FROM SNOW SURVEY DATA

OF

COLORADO RIVER APRIL-JULY RUNOFF NEAR GRAND CANYON

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Los Angeles Department of Water and Power - Power System
Power Operating and Maintenance Division
Research and Records Section

Again this year as last, this forecast is based on the assumption that the runoff of the Colorado River at the Grand Canyon gauging station during the April-July period is directly related to the April 1st water content of the snow cover at certain selected snow courses in the Colorado River Basin.

While the forecast by the Bureau of Reclamation, Office of River Control, is the official forecast used in scheduling the operation of Hoover Power Plant, forecasts from snow survey data can be made in advance of the time the official forecast is received and are helpful in setting up the preliminary power system schedules.

The forecast made from snow course data up to April 1, 1949 gives 11,100,000 acre-feet as the runoff during the 1949 April-July period. The method used here is not the result of exhaustive study, but has been found useful for the purpose already discussed and is described in the following paragraphs.

The average water content of the snow cover on each of seven major watersheds of the Colorado River was obtained from the April 1, 1949 Soil Conservation Service advance snow survey reports. The average water content for each watershed, expressed as a percentage of the nominal * fourteen year average (which also is given in the Soil Conservation Service Reports) was then weighted by a factor corresponding to the estimated normal contribution of each watershed to the flow near Grand Canyon. These factors were determined several years ago after detailed studies were made by this organization. The weighted average used to obtain the forecasted runoff figure is the sum of the individual adjusted water content values increased by the ratio of the estimated total percentage contribution of the seven watersheds to the total flow, taken as 100 per cent.

The water sheds estimated normal contribution to the Colorado River in percent, water content of snow in inches, water content as a percentage of the fourteen year average, and adjusted water content as a percentage of the fourteen year average are shown in the following tabulation.

* Some of the snow courses have less than 14 years of record.

Watershed	Estimated Percent Contribution to Colorado River	April 1, 1949 Water Content Inches	Water Content Percent of Nominal 14 Year Average	Water Content Adjusted Percent of 14 Yr. Avg.
Green River	11.17	15.2	123	13.7
Yampa "	14.62	22.5	124	18.1
White "	3.55	23.0	132	4.7
Colorado "	29.29	16.6	114	33.4
Gunnison "	15.60	21.8	120	18.7
Dolores "	7.88	10.7	141	11.1
San Juan "	15.66	29.2	143	22.4
Total	97.77	-	-	122.1

$$\text{Weighted Average (or forecast factor)} = \frac{122.1}{97.77} = 125\%$$

The weighted average water content of the seven watersheds expressed as a percentage of the fourteen year average is 125 percent. The thirteen year average of the April-July runoff, beginning in 1936 is 8,679,000 acre-feet.

To account for the effect of the 1949 period flow, a fourteen-year provisional average was found by using the forecast factor in a formula (which may be derived by use of simple algebra) and which gives the following result:

$$\text{The 14-year average} = \frac{(14 - 1)}{(14 - 1.25)} \times 8{,}679{,}000 = 8{,}840{,}000 \text{ acre-feet.}$$

Using this provisional 14-year average the forecasted flow is:

$$8{,}840{,}000 \times 1.25 = 11{,}100{,}000 \text{ acre-feet}$$

As a matter of interest, a comparison of forecasts made by this method with the actual runoffs for the years from 1945 to 1948 inclusive are given in the following tabulation:

Year	April-July Runoff Thousands of Acre-feet		Percentage of Error
	Forecasted	Actual	
1945	9480	8093	+ 17
1946	6120	5561	+ 10
1947	8240	9019	- 9
1948	9740	9491	+ 3

The results shown in the preceding tabulation give promise of continued usefulness of forecasts from snow course data as an aid to setting up schedules for power system operation.

FORECAST OF FLOR OF COLORADO RIVER
NEAR GRAND CANYON, COLORADO
April-July 1949

by Homer J. Stockwell, Irrigation Engineer
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Fort Collins, Colorado

Our forecast for the flow of the Colorado River at Grand Canyon for the April-July 1949 period is 10,900,000 acre-feet as indicated on April 1 snow surveys. The forecast is based on the percentage of normal snow water content on ten snow courses on the Colorado River watershed. They are listed as follows:

Wyo. No. 24 - Mulligan Park	Colo. No. 33 - Ind. Pass Tunnel
Wyo. No. 26 - Loomis Park	Colo. No. 35 - Burro Mountain
Colo. No. 19 - Tennessee Pass	Colo. No. 37 - M. F. Camp Ground
Colo. No. 25 - Lizzard Head Pass	Colo. No. 56 - Mesa Lakes
Colo. No. 29 - Upper San Juan	Colo. No. 58 - Ironton Park

It will be noted that these courses are so distributed over the Colorado River Watershed as to approximate the source of water from the various tributaries. It may also be stated that through a study of many combinations of snow courses on the watershed , the above gives about the best correlation without using detailed statistical analyses. The average of these courses was 19.9 inches on April 1, 1949 as compared to a thirteen year average for April 1 of 16.4. The percentage of normal is 121 percent. However due to the fact that the soil was dry last fall, and that runoff does not increase in the same proportion as snow water content, the estimate is 10,900,000 or about 114 percent of normal.

The snow fall during the month of April has a marked effect on runoff, but not as much as might be indicated by May 1 snow surveys. The May 1 forecast will be based on the same courses using the April and May snow water contents. The May 1 measurements will be given one-half the weight of those on April 1.

THE SNOW JEEP

by

George A. Lewis, Hydrographer
City of Los Angeles Department of Water and Power

Our need for some form of transportation that would suffice, not only for normal use, but also when severe storms temporarily close existing roads to the conventional type of vehicle, was responsible for the investigations of dual wheel equipment.

Prompted by experience with the regular Willys Jeep equipped with single snow tires, we decided to devise some sort of auxiliary equipment that would improve the use of these machines in snow and deep mud.

Dual wheels, both front and rear, equipped with steel grousers to further improve the traction, were constructed and their use has greatly improved the performance of these vehicles.

CONSTRUCTION

The original adaption was made by use of Army surplus materials, due to a general shortage of automobile parts at that time. Our present models are constructed by attaching Ford V-8 wheels, No. 68-1015, Model 77 to the standard Jeep equipment.

The dual wheels are made up as follows:

An auxiliary hub is constructed from a short section of a $7\frac{1}{2}$-inch O.D. iron pipe. A face plate is welded to one end of this section and this plate is machined and drilled to fit over the hub of the Jeep wheel. Welded to the other end of the casing is a 12-inch flanged facing, the latter being machined and drilled to fit the auxiliary Ford wheel. The hub is first attached to the Ford wheel by the use of standard lug bolts, and the combination is then bolted to the Jeep wheel with custom-made lug bolts, somewhat longer to accommodate the added thickness of the face plate. It is necessary to provide small cone shaped filler rings to fit around each bolt in the hub of the Jeep wheel. These rings fill the concave area around each bolt in the regular wheel and provide a flat bearing surface for the face plate of the auxiliary hub. The hub projects outward from the face of the regular wheel and forms a space for clearance between the two tires. This clearance must be maintained to prevent chafing and excessive heat generation in the dual tires while driving on oiled roads. It should not be more than one-half inch in order to provide maximum snow compaction. There is sufficient room within the hub casing to operate a T-handled lug wrench and the dual wheel can be attached with no difficulty. The time required to attach all four wheels is less than thirty minutes (two men). The effective width of the dual tire assembly is fourteen inches and the bearing pressure developed in snow is approximately 1.3 pounds per square inch.

During the initial test conventional type truck chains were used, and while results were fairly satisfactory, it was found that under adverse snow conditions (corn snow) the chains had a tendency to carve out a section around the circumference of the tire. The whole mass would then revolve with little tractive power. To overcome this the center section of each cross link of the chain was removed and 12-inch angle iron grousers welded in. This eliminated the trouble and greatly improved the traction. The chains used were Western Auto Supply single pneumatic truck, No. 6-1460, size 6.00 x 16. To prevent slipping of the tire inside the grousers a small toggle hook was developed which gave sufficient leverage to tighten the chain and grouser firmly against the tire.

Aside from the cost of spare wheels and grouser material (the extra tires are dismounted in summer season and can be used in other operations), the expense of constructing the complete job is best formulated in "shop man hours", the total time required was 68 man hours. The actual cost of the first experimental job was $287.40, with some time being lost in cut and try methods.

OPERATION

It was anticipated that some difficulty might be experienced in attempting to steer a Jeep equipped with dual wheels in front. It was found to be somewhat awkward at first, but the operators soon became accustomed to the feel of the machine and had no trouble traveling 45 to 50 miles per hour on the highway. In snow, sand, or mud, at low speeds, there is no noticeable difference in steering effort required. At medium speeds on the highway the machine has a slight tendency to wander, and requires a little more attention than with conventional equipment. One soon becomes used to the feel of the wheel, however, and steering becomes natural.

The initial tests of this machine were made without chains, then with chains, and finally with grousers. The use of the grousers was found to be beneficial under nearly all conditions. The first tests were conducted in the Mammoth area of Owens Valley in 93 inches of compact spring snow, the top 14 inches of which was freshly fallen powder.

At the end of a road previously cleared by snow plow, we were confronted by an eight-foot verticle bank and it became necessary to carve this off to an angle of 45 degrees. The ascent of this short slope was made without great difficulty, and the machine was maneuvered along the roadway for a considerable distance turning, stopping, and starting. The transmission was operated in low-low gear, and both axle drives were used. The power available with this hookup is far in excess of that necessary for traveling, but we soon learned that less slippage of the wheels occurred under low controlled speeds. The tests proved also that the wheels will spin in only to axle depth. When this occurred it was only necessary to tamp snow under each wheel and forward movement could be resumed. The design of the Jeep, high clearance and lack of fender obstruction, lends itself well to shoveling operations when it becomes necessary.

Snow compaction under the wheels was found to be very high. Measurements proved it to be even greater than that obtained by a specially designed machine under test in this area by Army Engineers. Their problem was to determine the feasibility of compacting air strips in heavy snow country.

At the conclusion of our test in the Mammoth area, we removed the grousers, drove the machine to a lower elevation and made further runs in compacted snow of lesser depth. We also tried the machine in cross-country traverses, over rocks, snow, and brush. In all of these trials the Jeep was given a very rigorous test. In fact we went out of our way to find difficult conditions. On several occasions the machine stalled momentarily, but it only required some maneuvering to get going again.

The primary purpose of our experiment was to develop auxiliary equipment for snow travel. Since these tests were so successful in snow, we decided to continue them under swamp and sand conditions. The machine was then tested in the swamp areas of Owens Valley, and the results were amazing. The Jeep readily negotiated mud, water and tulles. The bottom soil of the swamp area was soft, slick clay mud, and the machine traversed this without the least difficulty. The pace, however, was necessarily moderate. Grousers were used and the Jeep operated successfully in depths up to 18 inches of water.

Finally the machine was given a thorough test over soft, wind-transported sand dunes. In low-intermediate gear and using grousers, it negotiated sand dunes at an angle of 35 degrees without any difficulty. Actually I can foresee no need of traversing such country except in case of an emergency. The tests, however, did serve to establish what can be done if need be. In ordinary soft, level sand, the machine will travel in conventional high gear.

CONCLUSION

Gas and oil consumption was not checked during the tests, nor was any mileage data kept. There has been no indication from our experience that the use of dual wheels will greatly increase gas and oil consumption. On conclusion of the original tests the machine was returned to the shop for dismantling and inspection. No defects were found. The initial test, made over a period of six weeks, during which time the machine was otherwise in normal use of the Hydrographic Patrol indicated that use of dual wheels and grousers would be quite feasible. Three years of successful operation has since proven the combination to be very practical.

At the beginning it was assumed that bugs might develop in the machines after a long period of use. This, however, has not occurred. Only one failure (front transmission) has developed during our use of Jeeps equipped with dual wheels. Since the machines are used regularly throughout the balance of the year with the conventional wheel, it is probable that the failure may have occurred in any event. It is quite

likely that the factor of safety, built into the machine by the manufacturers, is sufficient to protect the design, even with the added strain of the dual wheels.

It should be noted that such equipment is not intended nor designed for cross-country use in deep, soft snow (over 30 inches). It is recommended for travel over established roadbeds, regardless of snow depth, wherever the snow is solidly packed or where the road can be traversed after each storm, to consolidate the cover. (In the Mammoth tests, one passage of the Jeep resulted in a high-gear road).

The Jeep equipped with dual wheels and grousers, is not to be compared with machines designed solely for snow transportation. Among these are the Tucker Sno-Cat, the Army Weasel and the M-7 Snow Tractor. These machines develop respectively .6, 1.5 and .8 pounds per square inch bearing pressure on the snow. However, our field tests have indicated that tractive power, not bearing value, is the criterion of successful snow transportation.

Machines designed solely for snow travel must often be transported to the snow fields by truck. The snow Jeep not only has a variety of normal uses, but can also be fitted to allow snow travel as outlined above in about 30 minutes. Its capacity in hard going over snowbound roads is limited to about three men and their snow survey equipment.

From a practical viewpoint, such use contributes greatly to the flexibility of ordinary equipment. For in addition to their constant use on regular jobs, they become the means of transportation during periods when other equipment cannot be used. In our experience these machines have enabled us to maintain travel in winter season to gaging stations and several snow survey courses. Many reaches of road which formerly required travel by ski, have now become available to mechanical transportation. This has resulted in a considerable saving of time and man power, as well as preventing the loss of hydrographic record which otherwise would not be obtained.

WATER SUPPLY FORECASTS BASED ON PRECIPITATION AS APPLIED TO THE COLORADO AND ADJACENT BASINS

by

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In 1942, the Weather Bureau initiated its water supply forecasting service in the Western States. For the past several years forecasts have been prepared using techniques which are based on precipitation-runoff relations. Inaugurating an expanded program of water-supply forecasting, the Weather Bureau, late in 1947, set up new forecast centers at Portland, Oregon, and Salt Lake City, Utah. These two centers, together with the Sacramento and Kansas City Offices prepare forecasts for the Colorado, Columbia, Missouri, Rio Grande, Sacramento-San Joaquin and Great Basins. Beginning the first of this year, these forecasts have been combined in a single bulletin.

Precipitation data (Fig. 1) from eleven Western States and British Columbia are collected by the various section centers and relayed by wire to the forecast centers. In all, data from 425 stations are used in preparing water supply forecasts for 250 points, issued as of the first of each month, January through May.

LIGHT and KOHLER (1) describe the forecasting technique which was developed in the initial studies conducted by the Weather Bureau. The procedure presently employed by the Weather Bureau is an outgrowth of this earlier technique. The Gunnison River Basin above Grand Junction (Fig. 2) has been selected to illustrate this procedure.

ADJUSTMENT OF PRECIPITATION AND RUNOFF DATA

In dealing with long-period records such as are involved in analyses of this kind, experience has shown the need for adjustment of the precipitation data if best results are to be obtained. LIGHT and KOHLER (1), STANLEY and KENNEDY (2) and MERRIAM (3) have described the double-mass plotting technique used to correct for changes in station location and exposure. Briefly, this technique involves the preparation of precipitation bases for the numerous sub-basins (Fig. 3) against which the records of individual stations may be compared. Records of ten or more selected long-period stations are used in making up these precipitation bases for each of the subareas. The winter (October-April) precipitation is accumulated for these base stations, beginning with the latest year of record. The mean of these accumulated values is the precipitation base.

As a precaution against including any erratic records in the base, the individual base station values are plotted against the precipitation base. If examination of the plotting shows decided or erratic changes in the slope of the curve for any station, that station is omitted and the base is recomputed.

Figure 4 shows the accumulated winter precipitation for each of the nine index stations used in the procedure for the Gunnison River Basin plotted against the precipitation base for the upper Colorado River area. Data from twenty stations make up this particular base.

Adjustments as indicated by the double-mass curves are applied to the earlier years of records bringing them in line with the most recent years. Investigation of the station histories will usually disclose changes in station location or other circumstances which correspond to the breaks in the slope of the double-mass curves.

Adjustments of a cimilar nature are usually required to offset the time trends which are apparent in many of the streamflow records in the West. There has been in the Western States in more recent years an almost universal decrease in runoff per unit of measured precipitation. KOHLER and LINSLEY (4) point out four factors to which these time trends in precipitation-runoff relations may be attributed:

> (1) a trend between actual and measured precipitation, (2) a downward trend in actual precipitation, (3) a trend between actual and measured runoff, and (4) increased water utilization and evaporation losses.

An initial adjustment of the runoff data can frequently be made by plotting the accumulated runoff values against the precipitation base. However, because the relation between precipitation and runoff is usually non-linear and/or does not pass through or near the origin, a more satisfactory adjustment procedure is to use a simple plot of the water-year runoff against the average October-April precipitation for the base stations (Fig. 5) on which a curve is drawn to fit the most recent years of record. A mass curve can then be plotted using the computed against the observed runoff and the adjustment factors determined from the ratio of the slopes of the segements of the curve. In the case of the Gunnison River (Fig. 6) there is a single break in the mass curve between the years 1930 and 31 with an adjustment factor of 0.83 indicated.

This is a preliminary adjustment to the runoff data. A second adjustment is made later following the development of the precipitation index.

DETERMINATION OF STATION AND MONTHLY WEIGHTS

In developing a precipitation-runoff forecasting relation, it is desirable to have a good areal distribution of index stations over the basin for which the forecast is to be made. Because of the sparsity of population, rugged topography and other features common to our Western States, a perfect network of precipitation stations is not available. There is however, for most of our Western basins an adequate long-period coverage of precipation records from which satisfactory forecasting relations may be derived, if streamflow records of reasonable length are available.

To take full advantage of the various precipitation stations in or near a basin in developing an index to seasonal runoff, it is essential

that a determination be made as to the relative importance of each station. For this purpose a multiple correlation of the total winter (October-April) precipitation at each of the selected stations with the adjusted water-year runoff from the basin is used to ascertain the weights to be assigned to the individual stations. Eight stations, numbers 2 through 9 of Figure 2, are used in deriving the regression equation for the Gunnison River Basin:

$$(1)\quad Q = -0.943 + 0.002P_2 - 0.023P_3 + 0.205P_4 + 0.103P_5 - 0.084P_6 + 0.090P_7 + 0.139P_8 + 0.001P_9$$

where $\underline{Q}$ is runoff in million acre-feet, P_n is October-April precipitation in inches, and the subscripts designate stations (Fig. 2).

Station weights, the summation of which is made to equal 1.0, are assigned on the basis of the relative magnitude of the regression coefficients. The intercorrelation of the precipitation values at adjacent stations tends to magnify the variation in the regression coefficients. Therefore the coefficients are used only as a guide in determining the station weights. Stations which have small negative coefficients may be assigned small positive weights, such as the case of the Crested Butte and Montrose stations. Stations which have large negative coefficients are dropped from the analysis.

To represent the headwaters of the Uncompahgre in the Gunnison Basin, Ames (station 1, Fig. 2) was introduced in the group of index stations and arbitrarily assigned a weight. It is pointed out that this is a practice that is not ordinarily followed, but in this case meant a considerable saving in time.

The summation of monthly precipitation values for the nine index stations multiplied by the respective station weights is the effective monthly precipitation. For the Gunnison River Basin:

$$(2)\quad E = 0.08P_1 + 0.07P_2 + 0.04P_3 + 0.25P_4 + 0.15P_5 + 0.04P_6 + 0.10P_7 + 0.20P_8 + 0.07P_9$$

The coefficient, 0.80, of a simple linear correlation between the October through April effective precipitation and the adjusted runoff compares favorably with the coefficient, 0.83, of the multiple correlation performed above, and indicates that reasonable weights were assigned to the index stations.

A procedure similar to that used in determining station weights is followed in assigning monthly weights. Monthly weighting is necessary to account for variations in the effectiveness of precipitation occurring at different times of the year. Multiple correlation of the effective precipitation for each month, October through May, against the adjusted runoff is used to determine the monthly weights. The September and June weights as well as the October through May weights are assigned on the basis of the trend exhibited by the October-May regression coefficients. The sum of the monthly weighs September through June is made to equal 1.00.

The monthly precipitation index is derived by multiplying the monthly effective precipitation by the monthly weight. The sum of the monthly

precipitation indices is the seasonal precipitation index, Z.

$$(3)\quad Z = 0.06E_0 + 0.07E_1 + 0.08E_2 + 0.09E_3 + 0.11E_4 + 0.13E_5 + 0.14E_6 + 0.13E_7 + 0.11E_8 + 0.08E_9$$

where the subscripts 0 through 9 designate the months September through June, respectively.

"CARRY-OVER" EFFECT

To account for the "carry-over" effect, that is, the contribution which ground water from previous years' precipitation may make to runoff in any particular year, a multiple correlation of the runoff against the precipitation index of the corresponding year and that for the previous year is performed, for which the general equasion is:

$$(4)\quad Q = a + b_1Z + b_2Z \text{ prev. yr.}$$

The ratio of the regression coefficients, b_2/b_1, is a measure of the "carry-over" from the previous year. If this ratio is greater than 0.25, a second correlation is performed, using two or more previous years' indices, to determine if the "carry-over" effect extends beyond the next previous year.

For the Gunnison Basin, b_1 and b_2 are computed to be 0.2549 and 0.0333, respectively, and the resulting ratio is 0.13. On the basis of this ratio, a weight of 0.1 is assigned to the previous year's index. No significant "carry-over" is apparent beyond the first year. The total precipitation index for any year is then the sum of the September-June precipitation index plus 0.1 x previous year's index.

$$(5)\quad I_1 = Z_1 + 0.1\ Z_0$$

FINAL RUNOFF ADJUSTMENT

A final runoff adjustment is now performed. The procedure is similar to that used in the initial adjustment except that the total precipitation index can now be used in place of the mean precipitation of the base stations. Observed runoff is plotted against the total precipitation index and a curve is fitted to the data of the later years (Fig. 7). Figure 8 is the doublemass plotting for this final runoff adjustment. In this procedure, the adjustment factor determined here, 0.78, is only slightly different than that indicated in the preliminary adjustment.

Following the final adjustment of the runoff data, the precipitation indices are plotted against the adjusted runoff and a curve fitted to the points (Fig. 9). This graphical relation is the forecasting curve for the basin.

FORECASTING FROM RELATION

The relation thus established lends itself easily to early season forecasts, an essential feature if full advantage is to be taken of water-

supply forecasting. As is common to most of the forecasting techniques currently in use, an assumption must be made as to precipitation for the balance of the season, that is, from date of forecast to end of June. But, whereas most other techniques are limited to a forecast based on the assumption of normal or average precipitation for the balance of the season, the Weather Bureau procedure permits forecasts based on the assumption of median, maximum, minimum, quartiles or any other specified values of precipitation occurring during the balance of the season.

From an analysis of past records, partial precipitation indices are derived. That is, the accumulated monthly indices from June back through each month are computed for each year of record and arranged in order of magnitude. Median, maximum, minimum and quartile values of the partial indices are thus obtained which are expressions of future precipitation which have known probabilities of occurrence. Figure 10 gives these partial precipitation indices for the Gunnison Basin for the period 1910-45.

Figure 11, the seasonal forecasting sheet, illustrates the computations involved in preparing the forecasts. The total indices are obtained by combining the accumulated monthly index values based on observed precipitation with the partial indices for the remainder of the season adding the "carry-over" effect from the previous year.

In addition to the basic forecast assuming median precipitation for the remainder of the season, estimates can be made based on the assumption that precipitation for the balance of the season will equal the maximum, minimum or quartile values of record. As pointed out by Bernard (5), most operational plans can be held within the range between the upper and lower quartiles. Yet there are those interests which have a definite need for the estimates of possible extremes. For instance, the demands of flood control operation and the decidedly different demands of power generation illustrate some of the uses which may be made of the maximum and minimum estimates. The opportunity afforded the water user to select the estimate best suited to his particular needs is a distinct advantage.

REFERENCES

1. LIGHT, PHILLIP and KOHLER, M.A., Forecasting seasonal runoff by statistical methods, Trans. Amer. Geophys. Union, vol. 24, pp. 719-736, 1943.

2. STANLEY, J. W. and KENNEDY, R. E., Forecasting Colorado River flow, Trans. Amer. Geophys. Union, vol. 28, pp. 766-779, 1947.

3. MERRIAM, CARROLL F., A comprehensive study of the rainfall on the Susquehanna Valley, Trans. Amer. Geophys. Union, pp. 471-476, 1937.

4. KOHLER, M. A. and LINSLEY, R. K., Recent developments in water supply forecasting from precipitation.

5. BERNARD, MERRILL, The long-term precipitation-runoff relation as a basis for forecasting water supply, presented at Amer. Geophys. Union Meeting, Cambridge, Mass., September 1947.

Fig. 1. NETWORK OF WEATHER BUREAU STATIONS IN WESTERN UNITED STATES

Fig. 2. GUNNISON RIVER ABOVE GRAND JUNCTION, COLORADO

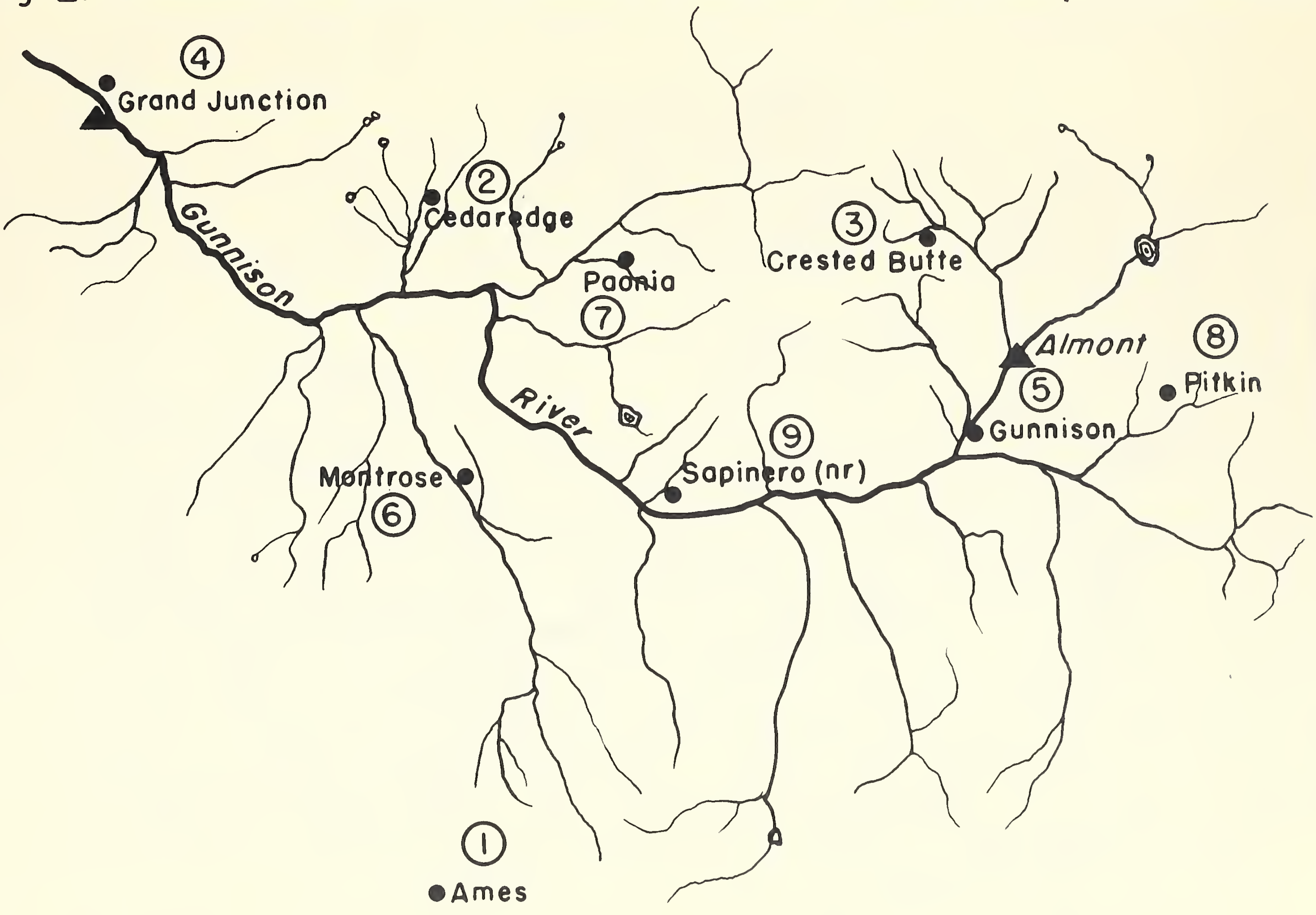


FIG. 3. SUBDIVISION OF WESTERN STATES
FOR ADJUSTMENT OF PRECIPITATION DATA

Fig. 4. DOUBLE-MASS PLOTTING FOR PRECIPITATION ADJUSTMENTS (UPPER COLORADO RIVER, 1910-45)

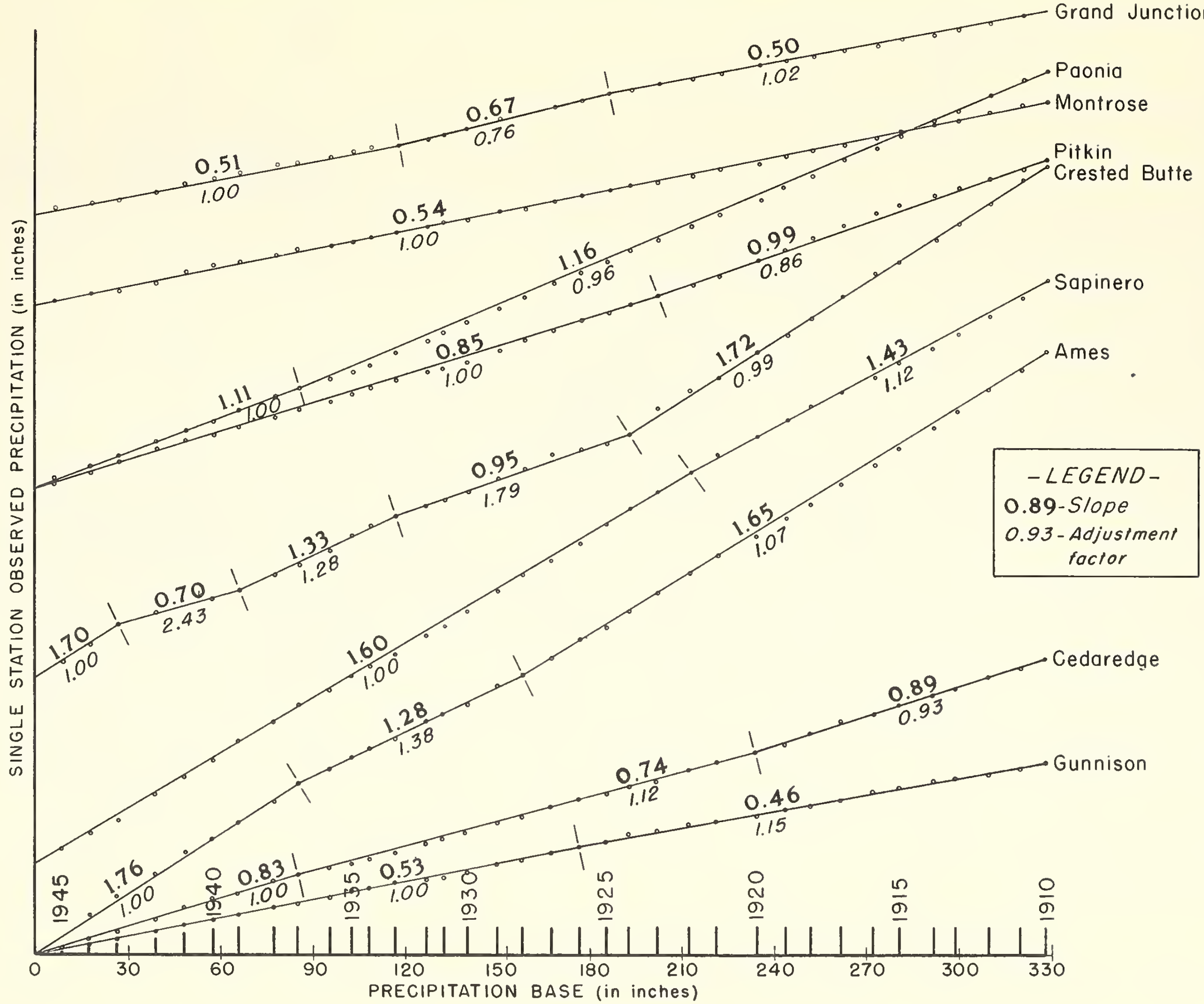


Fig. 5. PRECIPITATION-RUNOFF PLOTTING FOR PRELIMINARY ADJUSTMENT
(GUNNISON RIVER NEAR GRAND JUNCTION, COLORADO)

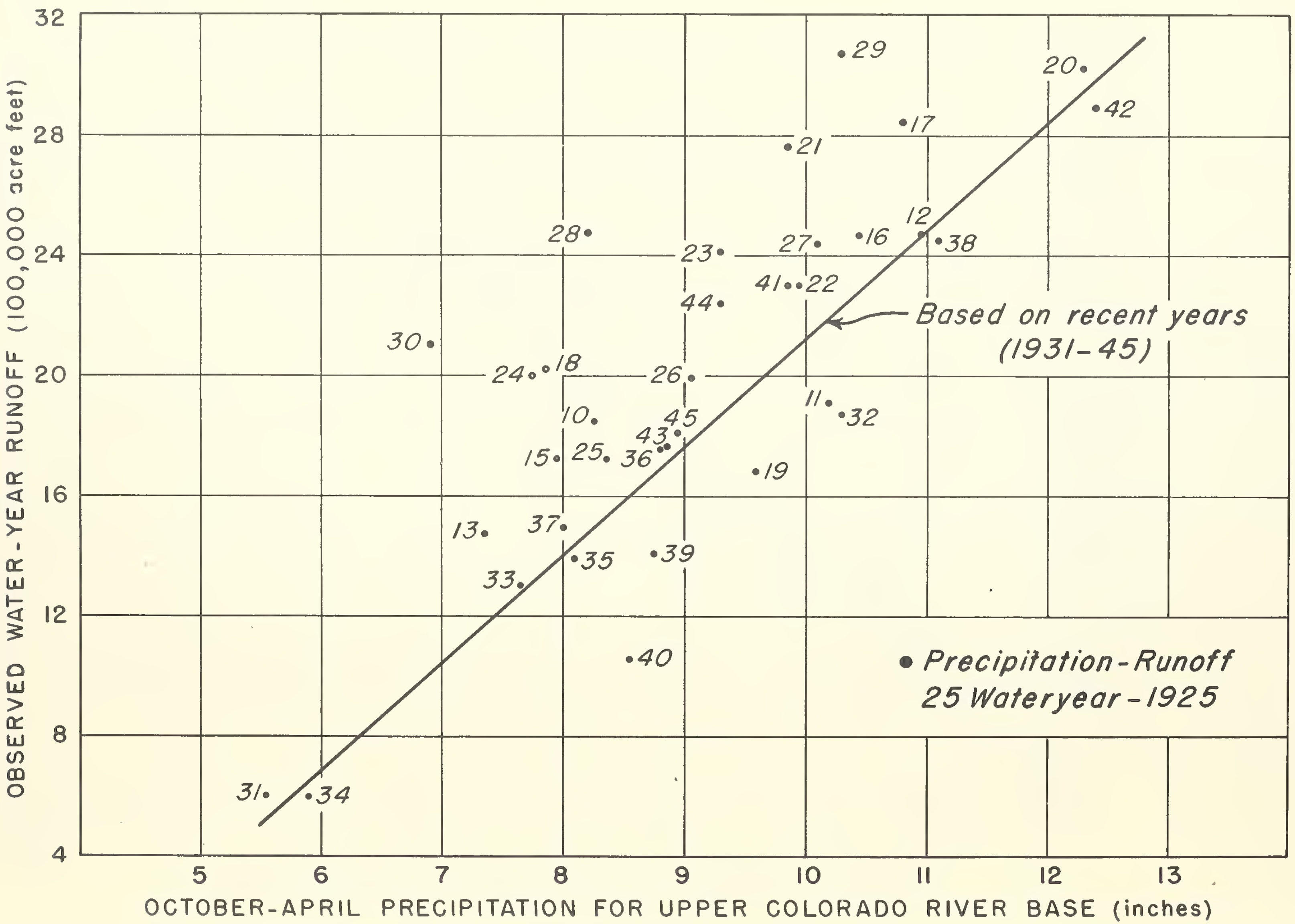


Fig. 6. DOUBLE-MASS PLOTTING
FOR PRELIMINARY RUNOFF ADJUSTMENT
(GUNNISON RIVER NEAR GRAND JUNCTION, COLORADO)

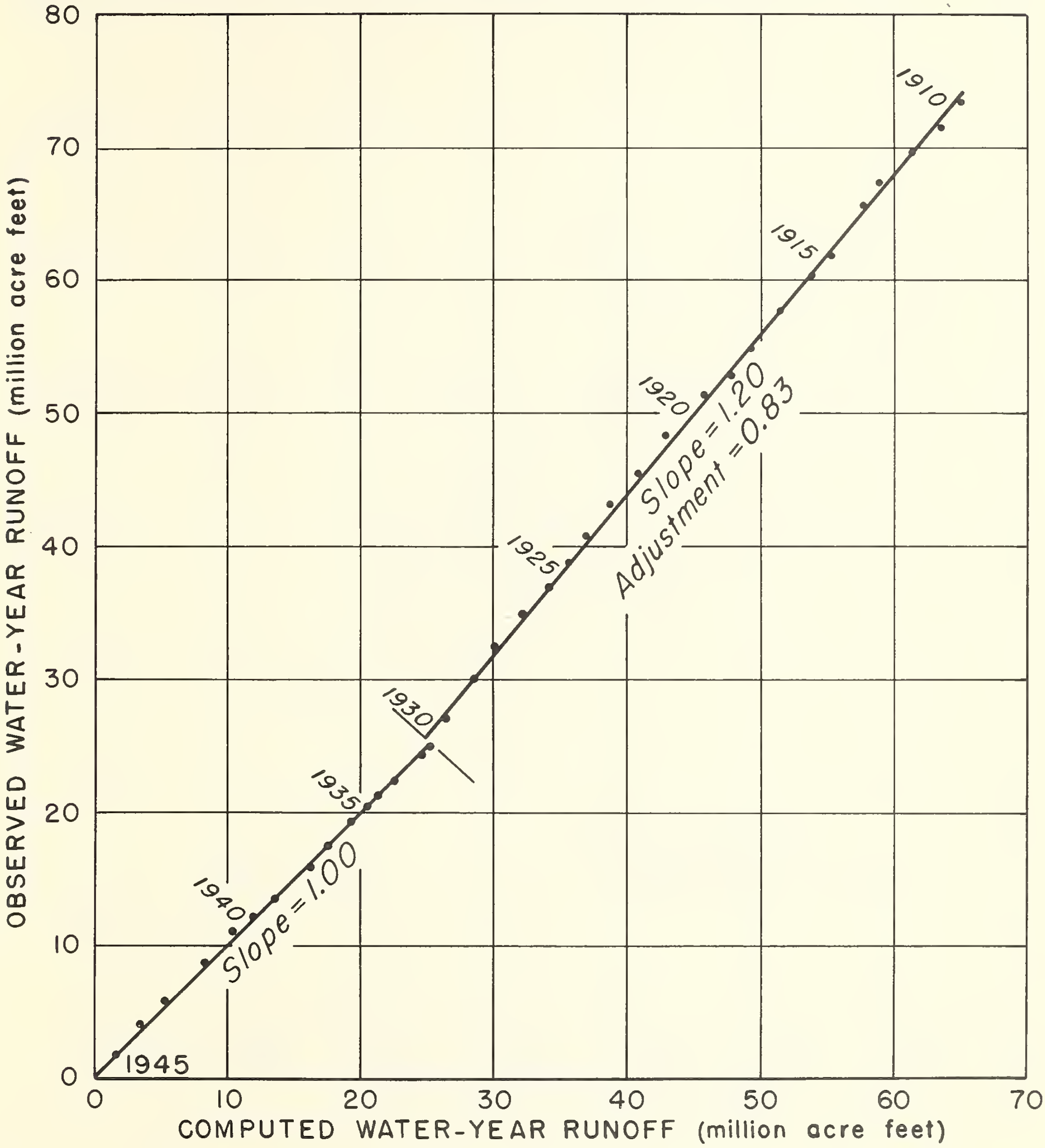


Fig. 7. PRECIPITATION-RUNOFF PLOTTING
FOR FINAL RUNOFF ADJUSTMENT
(GUNNISON RIVER NEAR GRAND JUNCTION, COLORADO)

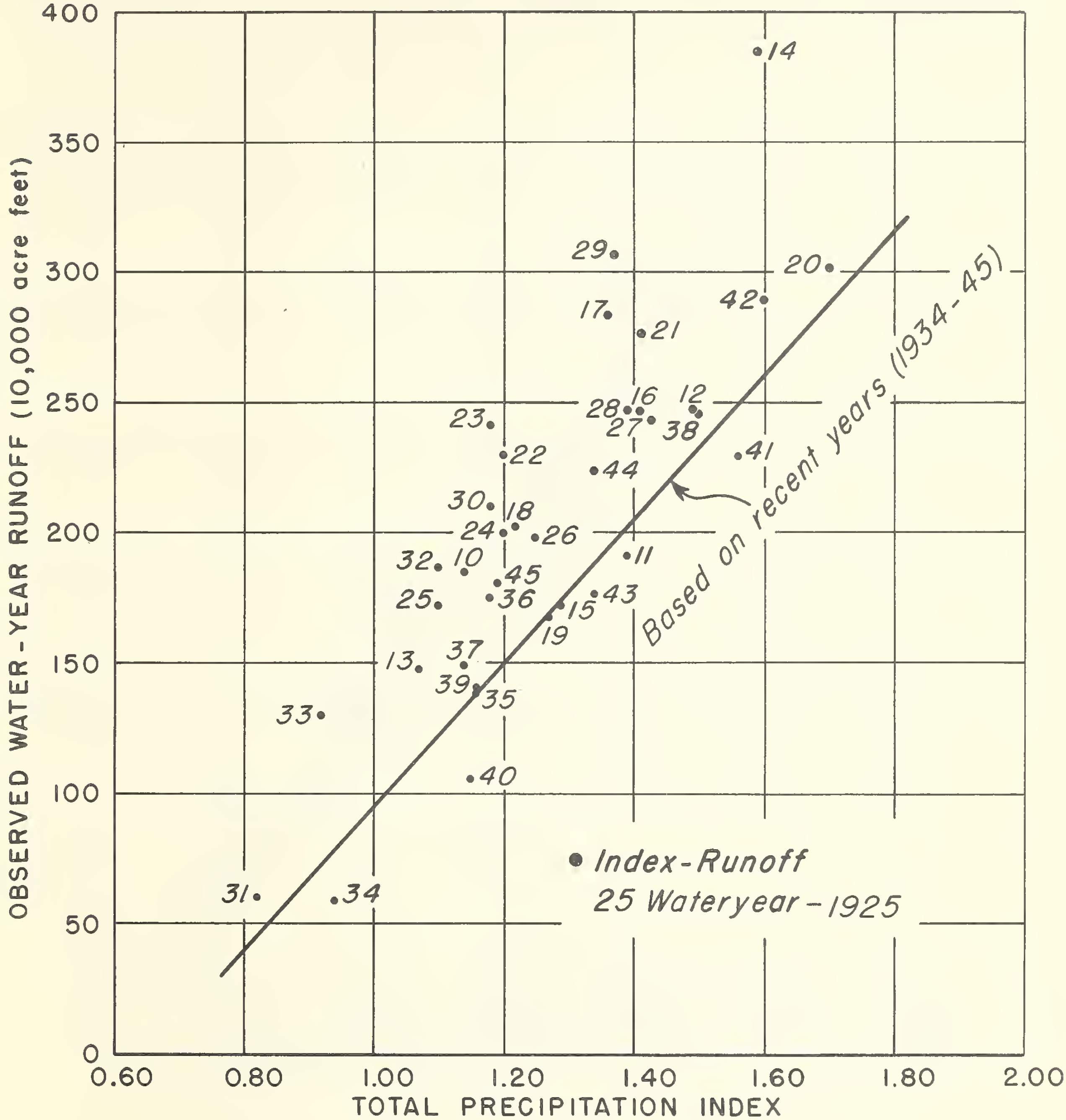


Fig. 8. DOUBLE-MASS PLOTTING
FOR FINAL RUNOFF ADJUSTMENT
(GUNNISON RIVER NEAR GRAND JUNCTION, COLORADO)

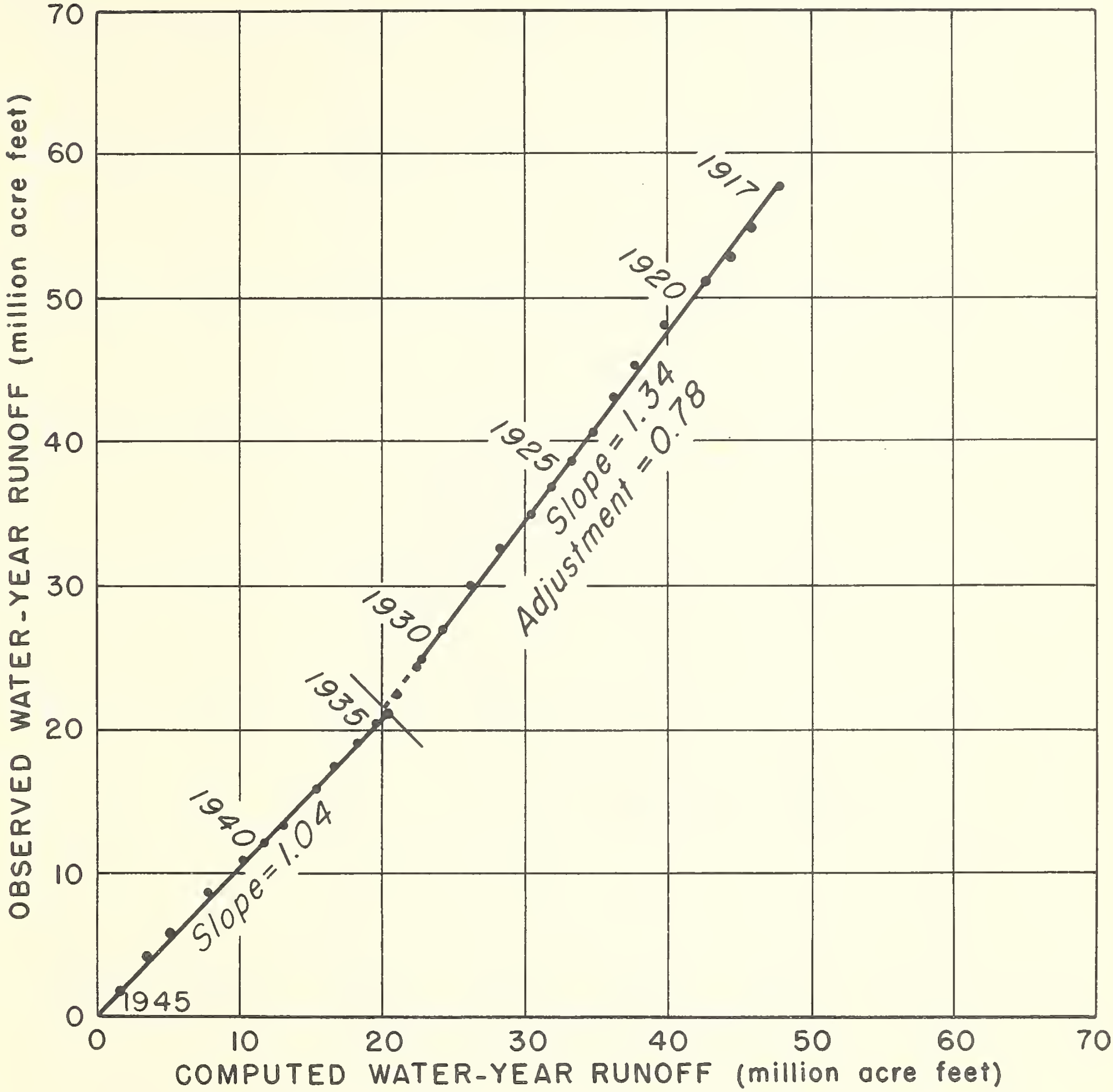


Fig. 9. FINAL PRECIPITATION-RUNOFF RELATION FOR THE GUNNISON RIVER NEAR GRAND JUNCTION, COLORADO

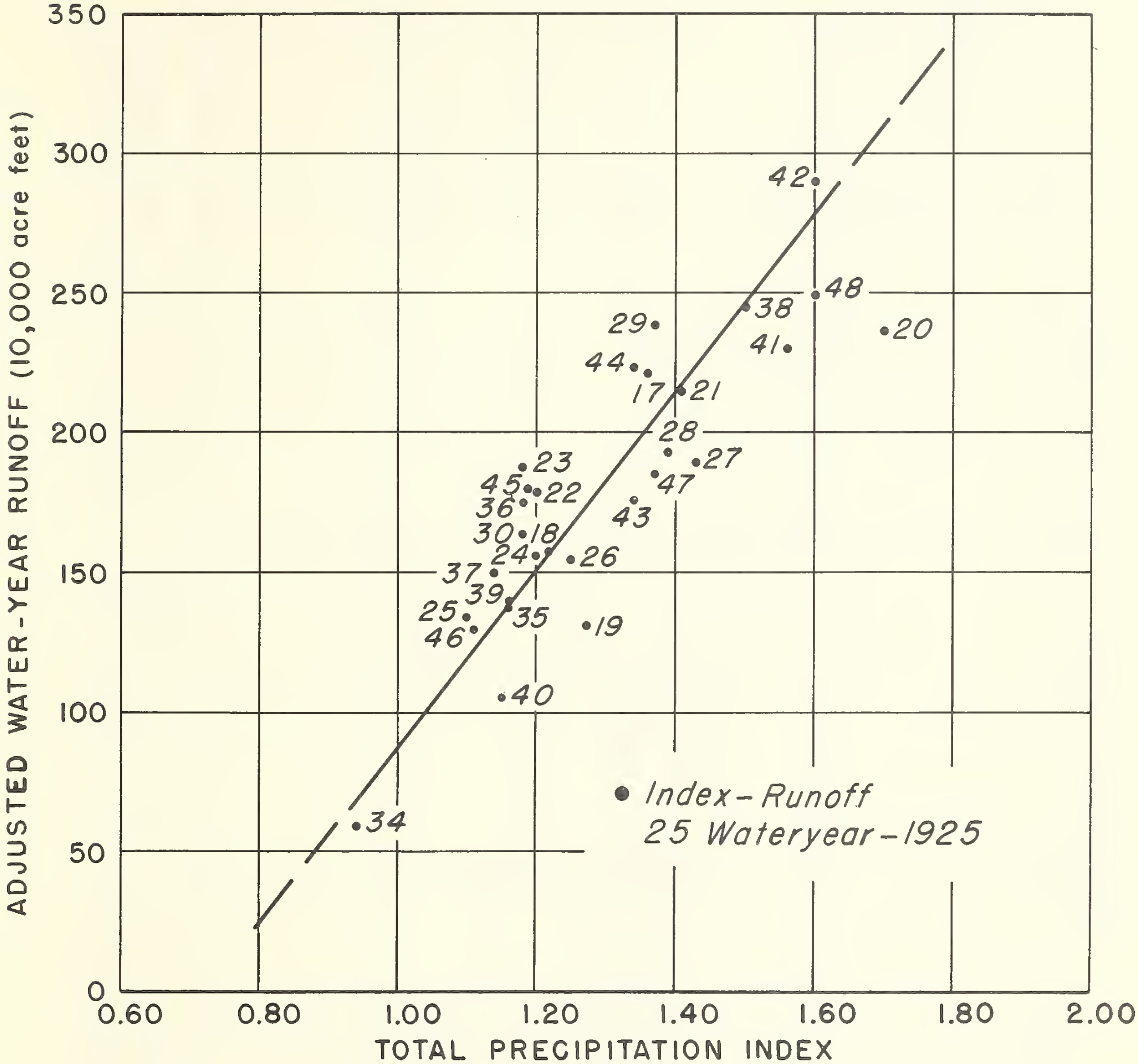
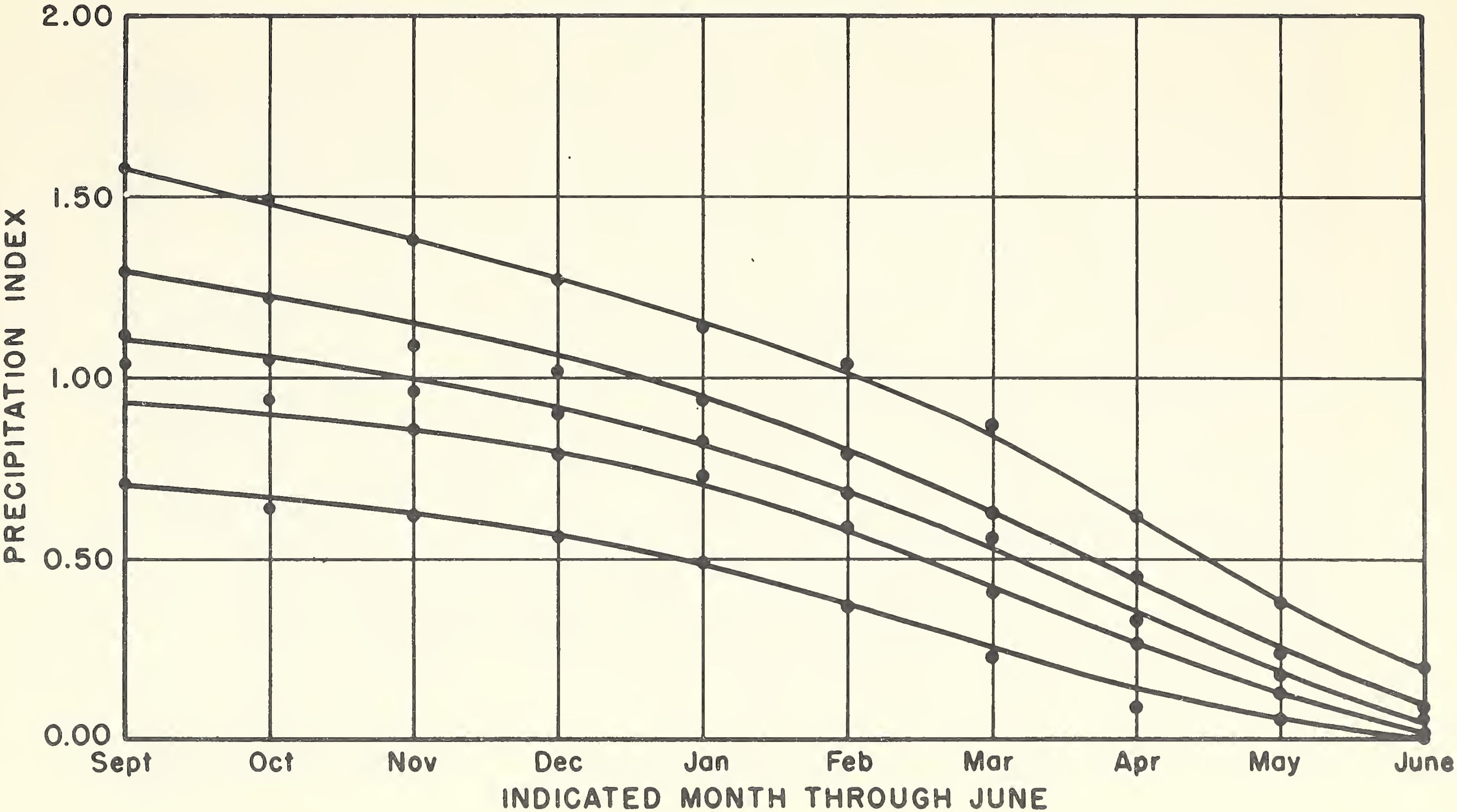


Fig. 10. SMOOTHING OF PARTIAL PRECIPITATION INDICES (GUNNISON RIVER NEAR GRAND JUNCTION, COLORADO)



U. S. DEPARTMENT OF COMMERCE | WEATHER BUREAU

DIVISION OF CLIMATOLOGICAL AND HYDROLOGIC SERVICES

FIG. 11 COMPUTATION OF SEASONAL WATER SUPPLY FORECASTS

Gunnison River near Grand Junction

1948-49 Water Year Runoff in 10,000 Acre-Feet

COMPUTATION OF EFFECTIVE BASIN PRECIPITATION

STATION	WGT.	SEPT Obs.	SEPT Wgtd.	OCT Obs.	OCT Wgtd.	NOV Obs.	NOV Wgtd.	DEC Obs.	DEC Wgtd.	JAN Obs.	JAN Wgtd.	FEB Obs.	FEB Wgtd.	MAR Obs.	MAR Wgtd.	APR Obs.	APR Wgtd.	MAY Obs.	MAY Wgtd.	JUNE Obs.	JUNE Wgtd.
Ames	0.08	1.02	.08	1.06	.08	1.50	.12	1.69	.14	4.74	.38	1.54	.12								
Cedaredge	0.07	.67	.05	.85	.06	.63	.04	1.21	.08	1.27	.09	.16	.01								
Crested Butte	0.04	1.02	.04	1.38	.06	1.88	.08	3.68	.15	3.23	.13	3.77	.15								
Grand Junction	0.25	.46	.12	.57	.14	.70	.18	.70	.18	1.33	.33	.40	.10								
Gunnison	0.15	.39	.06	.10	.02	.75	.11	.97	.15	1.16	.17	.77	.12								
Montrose	0.04	.44	.02	.27	.01	.59	.02	.48	.02	1.84	.07	.27	.01								
Paonia	0.10	.98	.09	.70	.07	1.47	.15	1.39	.14	2.39	.24	1.34	.13								
Pitkin	0.20	.40	.08	.80	.16	1.20	.24	1.90	.38	1.50	.30	2.00	.40								
Sapinero	0.07	.80	.06	.35	.02	1.60	.11	1.70	.12	4.10	.29	1.95	.14								
Effective Precip.(Σ)	1.00	—	.60	—	.62	—	1.05	—	1.26	—	2.00	—	1.18	—		—		—		—	

COMPUTATION OF FORECASTS (as of 1st day of following month)

		SEPT SPI	SEPT Q	OCT SPI	OCT Q	NOV SPI	NOV Q	DEC SPI	DEC Q	JAN SPI	JAN Q	FEB SPI	FEB Q	MAR SPI	MAR Q	APR SPI	APR Q	MAY SPI	MAY Q	JUNE SPI	JUNE Q
Monthly Weight		.06		.07		.08		.09		.11		.13		.14		.13		.11		.08	
Monthly Index .15		.04		.04		.08		.12		.22		.15									
Accumulated Monthly Index *		.19 *		.23		.31		.43		.65		.80									
Statistical Data for Balance of Year 1.56	Max	1.48		1.38		1.27		1.15		1.01		.83		.62		.38		.20		-	
1.29	U. Qrtl.	1.22		1.15		1.06		.95		.81		.63		.44		.25		.10		-	
1.10	Median	1.06		1.00		.92		.81		.68		.51		.33		.18		.06		-	
.93	L. Qrtl.	.90		.86		.79		.70		.59		.42		.27		.13		.02		-	
.70	Min.	.67		.63		.56		.48		.37		.25		.15		.06		.00		-	
	Variable	SPI	Q	SPI	Q	SPI	Q	SPI	Q	SPI	Q	SPI	Q	SPI	Q	SPI	Q	SPI	Q	SPI	Q
Total Seasonal Values	Max	1.67	300	1.61	280	1.58	270	1.58	270	1.66	295	1.63	285								
	U. Qrtl.	1.41	215	1.38	205	1.37	205	1.38	205	1.46	235	1.43	225								
	Median	1.25	167	1.23	161	1.23	161	1.24	162	1.33	192	1.31	185								
	L. Qrtl	1.09	117	1.09	117	1.10	117	1.13	129	1.24	163	1.22	157								
	Min	.86	44	.86	44	.87	47	.91	60	1.02	94	1.05	104								
0.0054054	Max.							146		159		154									
Flow in	U. Qrtl.							111		127		122									
% Normal (1920-44)	Median	90		87		87		88		104		100									
	L. Qrtl.							70		88		85									
1,850,000 A.F.	Min.							32		51		56									

* Includes 0.1 x Previous Years Index (0.1 x 1.47 = .15)

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File HYDI. 45206

A METHOD OF PREDICTING INFLOW TO LAKE MEAD DURING THE MONTH OF JULY

by

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Introduction

The operation of Hoover Powerplant and Lake Mead for the multiple purposes of flood control, irrigation and domestic uses, and power production requires the extensive use of inflow forecasts. General operating criteria have been established that on April 1 of each year a total of at least 9,500,000 acre-feet below elevation 1229 shall be available to store flood season runoff. In addition, after August 1 the requirement has been established that a total of 2,500,000 acre-feet will be kept available as a precaution against possible large rain floods which may occur above Lake Mead after August 1.

Operation for power production is last in priority among the multiple purposes of Hoover Dam. But, since power revenues are primarily responsible for repaying the construction and operation and maintenance costs of Hoover Dam, close attention is required to assure every effort is made to put all of the water passing Hoover Dam through the powerplant. In this effort limitations of installed capacity and storage capacity are the important factors with the restriction that severe withdrawal of stored water must be avoided in order to protect irrigation and power interests in future dry years.

The basic requirement of any forecast used for operational purposes is that the error be as small as possible. If perfect forecasts could be prepared operational problems would be minor, but since this is not the case methods of operation versatile enough to handle inflow that may possibly occur must be used.

The April 1 forecast issued by the Office of River Control has the possible error of plus or minus 2.9 million acre-feet from the mean forecasted value. The difference between the maximum and minimum forecast is of such magnitude that in most cases bypassing of water around Hoover Dam would be necessary if maximum inflow occurs or there would be a deficient holdover storage if minimum inflow is experienced. With this situation in mind a method of predicting inflow to Lake Mead with the object of obtaining a more accurate determination of actual inflow that is occurring as soon as possible during the flood season would be of utmost value for operational purposes. This paper is presented to explain the method used in forecasting inflow, during the latter part of the spring runoff period. By means of these forecasts, it is possible to predict the remainder of the spring inflow within progressively narrower limits between June 20 and the end of July, and to use

such data in planning operations of Hoover Dam and Powerplant so as to avoid high releases which might be required if actions were delayed, or to avoid unnecessary wasting of water in the event actual spring runoff did not reach earlier predictions.

Search for Methods of Forecast

Inspection of hydrographs for the Colorado River near Grand Canyon, Arizona, (the point of inflow measurements to Lake Mead) reveals that the peak discharge during the flood season runoff practically always occurs before the end of June. Also, after this peak inflow is reached a gradual decline of discharge follows, except for minor peaks due to rain floods which may occur from storms over the drainage basin during the latter part of June and the month of July. This observation indicates the fundamental principle underlying the method herein presented, namely that the decline of river discharge is on the average symmetrical enough to permit projecting the curve for a period in the future to give an estimate of total flow from the initial day of such a forecast to July 31.

The initial forecast method used by this office was made by the use of a normal recession curve principle, starting with the observed river flow on June 30 and estimating the flow for each following day during the month of July and thereby obtaining a forecast of inflow for the month of July. Plates 1 and 2 show the normal recession curve used in this method. Plate 1 shows the lower portion of the recession curve using a magnified scale; Plate 2 shows the upper portion of the curve. In use, the chart is entered on the ordinate with observed flow on June 30 and the estimated flow 24 hours later read on the abscissa. This process is continued from the starting day, re-entering the chart with each reading taken from the abscissa until estimated flows are made for each day throughout the month of July. Totaling the daily estimates gives the forecasted inflow during July. An example of the use of this method for July 1948 is given on Plate 3. Actual observed inflow is shown by the block diagram; estimated flow for each day is indicated by the curve. The preliminary estimate made on July 1 was revised on July 3 after a minor increase in flow on July 1 and 2, which was probably due to precipitation from a storm over the upper drainage basin on June 21 and 22, 1948. Forecasted inflow using this method gave an error of 9.1 percent below the actual observed inflow.

As this forecast procedure indicated a definite relationship between flow on June 30 and the resultant total inflow during the month of July, the next relationship intimated was a correlation of June 30 inflow and total inflow for the month of July. A simple correlation of average daily June 30 flow in cubic feet per second and total July runoff in acre-feet at Grand Canyon, Arizona, was made using all years for which records were available, namely 1923 through 1947. The first assumption was that the relationship between the two variables would be a straight line. Results of the linear correlation were highly significant; a coefficient of correlation, $R = 0.94$; and the coefficient of determination, $d = 0.88$. The coefficient of determination of 0.88 shows that 88 percent of the variability of the total July inflow in

acre-feet is accounted for in using the average daily flow at Grand Canyon on June 30. This correlation resulted in a nine out of ten probability range of 370,200 acre-feet, or in other words, in any future forecast there are nine chances out of ten that the actual value of runoff will fall within a range of plus or minus 370,200 acre-feet of the forecasted value. The next step considered was whether a straight line is adequate or if a better correlation could be obtained using a curvilinear relationship. Several curves were tried and the one having the highest correlation is given graphically on Plate 4. The best fit of the data was obtained with the smooth freehand curve shown. A curvilinear relationship is considered logical as the normal recession curve indicates a rather steep decrease in day to day flow when high values are experienced, flattening out considerably with low flows. Also, if the flow on June 30 is zero, it is illogical that a forecast of zero inflow would be made for the total month of July. The logical assumption is that the curve should rise steeply at first and then less and less sharply, thus approaching an asymptote. The coefficient of determination of the curve was, d = 91, compared to, d = 88, for the straight line correlation. This indicates an increase of 3 percent of the variability of July inflow is accounted for by using a curvilinear rather than a linear relationship. Also, the nine out of ten probability range was lowered from 370,200 acre-feet to 321,600 acre-feet with the curvilinear correlation. The curvilinear relationship has been adopted for use, rather than the straight line correlation, for forecasting July inflow because of the lower range of possible error of the forecasted value from the actual. The 1948 July inflow forecast, using Plate 4, would have been in error by 7.8 percent below the actual observed inflow.

The curvilinear relationships between average daily initial flow and total flow for the periods June 20 through July 31; July 10 through July 31; and July 20 through July 31; were computed and are shown graphically on Plate 5. The variables of average daily flow and total flow have been interchanged from ordinate and abscissa as shown on Plate 4, however, the June 30th curve on Plate 5 indicates identical values with the mean curve on Plate 4. The nine out of ten probability of these correlations range from 999,500 acre-feet on June 20 to 121,800 acre-feet on July 20 for the forecast period from the initial date through July 31. The coefficient of correlation varies from 0.69 to 0.95, the highest correlation being obtained for the June 30 curve. This chart is of value in indicating inflow expected through July 31 from as far ahead as June 20.

A comparison of forecasts using the above methods for the year 1948 are as follows:

	Forecasted Inflow Acre-Feet	Actual Inflow Acre-feet	Percent Error from Actual
Using Recession Curve on July 1 (Plates 1 & 2)	761,700	1,009,000	- 24.5
Using Recession Curve Adjusted to July 3 (Plates 1 & 2)	916,800	1,009,000	- 9.1
Curvilinear Correlation (Plate 5)			
On June 21	2,235,000	1,648,000	+ 35.6
On July 1	930,000	1,009,000	- 7.8
On July 11	645,000	520,300	+ 23.9
On July 20	250,000	219,400	+ 13.9

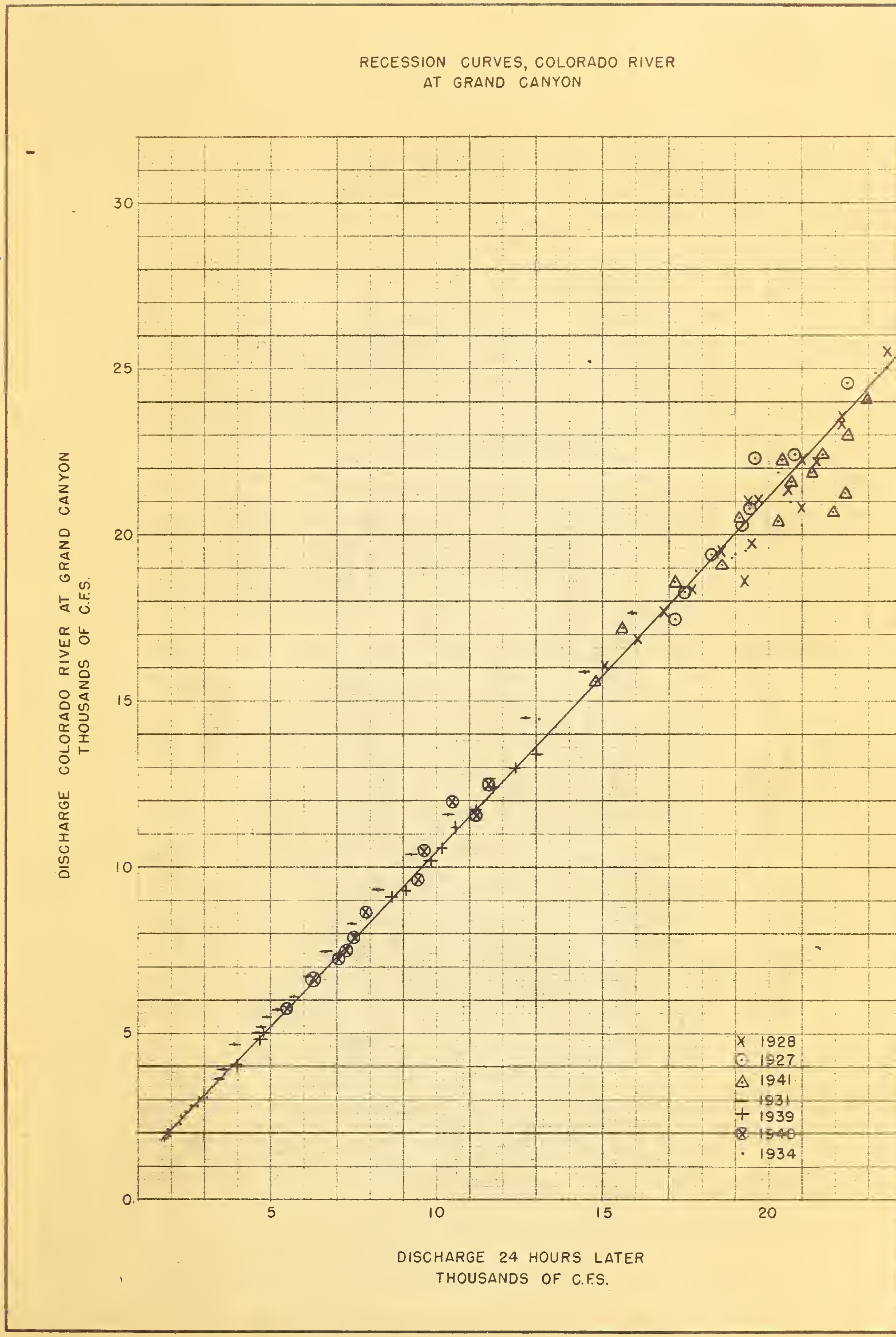
Conclusions

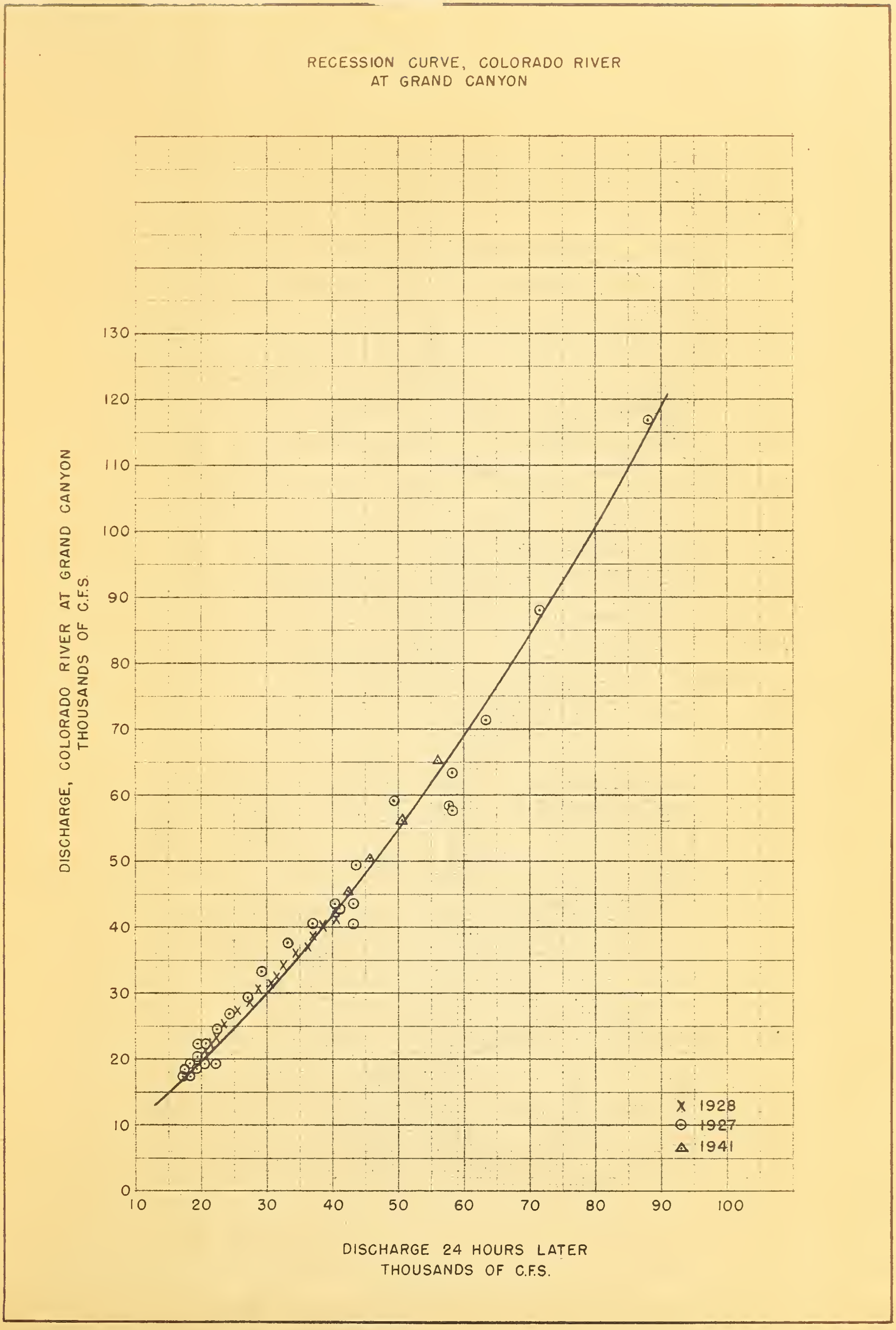
For better operational control of Hoover Powerplant and Lake Mead the use of inflow forecasts during the month of July is of utmost value. In many cases the problem of whether bypassing will be necessary may be solved by use of the July forecasts, as operation plans adopted in April or May do not usually call for bypassing until July 1 and only then if the maximum forecasted inflow occurs. Use of this method may indicate as far in advance as June 20 the expected total inflow for the April through July period and aid in determining whether maximum or minimum conditions of inflow, as indicated by earlier forecasts, are being experienced.

The recession curve is somewhat more versatile and may be used in predicting day by day flow with adjustments for minor peak flows that may be experienced. Forecasts made from the recession curve are usually below the actual observed as the curve approximates an envelope curve of the minimum expected runoff. Any minor peaks in streamflow due to local rain runoff will result in actual flows exceeding the forecast.

The correlation curves provide a means of forecasting the residual inflow expected through July 31 and are an accurate and fast method of forecasting this flow from data readily available. They are of utmost value for determining whether maximum, mean, or minimum forecasted inflow, as indicated by earlier forecasts for the April-July period, is occurring, and make possible improved operational planning by the Office of River Control.

The methods presented in this paper, in addition to inflow forecasts made by the Office of River Control for the April through July period, have proven their value for operation of Hoover Powerplant and Lake Mead for the purposes of flood control, irrigation, and power production. However, there is considerable left to be desired in the accuracy of all forecasts. Methods of improving forecasting techniques, so as to secure greater accuracy and utility for operational use, are constantly being sought, whenever personnel can be assigned to such research.


RECESSION CURVES, COLORADO RIVER
AT GRAND CANYON
DISCHARGE COLORADO RIVER AT GRAND CANYON
THOUSANDS OF C.F.S.
30
25
20
15
10
5
0.
5
10
15
20
DISCHARGE 24 HOURS LATER
THOUSANDS OF C.F.S.
1928
1927
1941
1931
1939
1940
1934


RECESSION CURVE, COLORADO RIVER
AT GRAND CANYON
DISCHARGE, COLORADO RIVER AT GRAND CANYON
THOUSANDS OF C.F.S.
0
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40
50
60
70
80
90
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130
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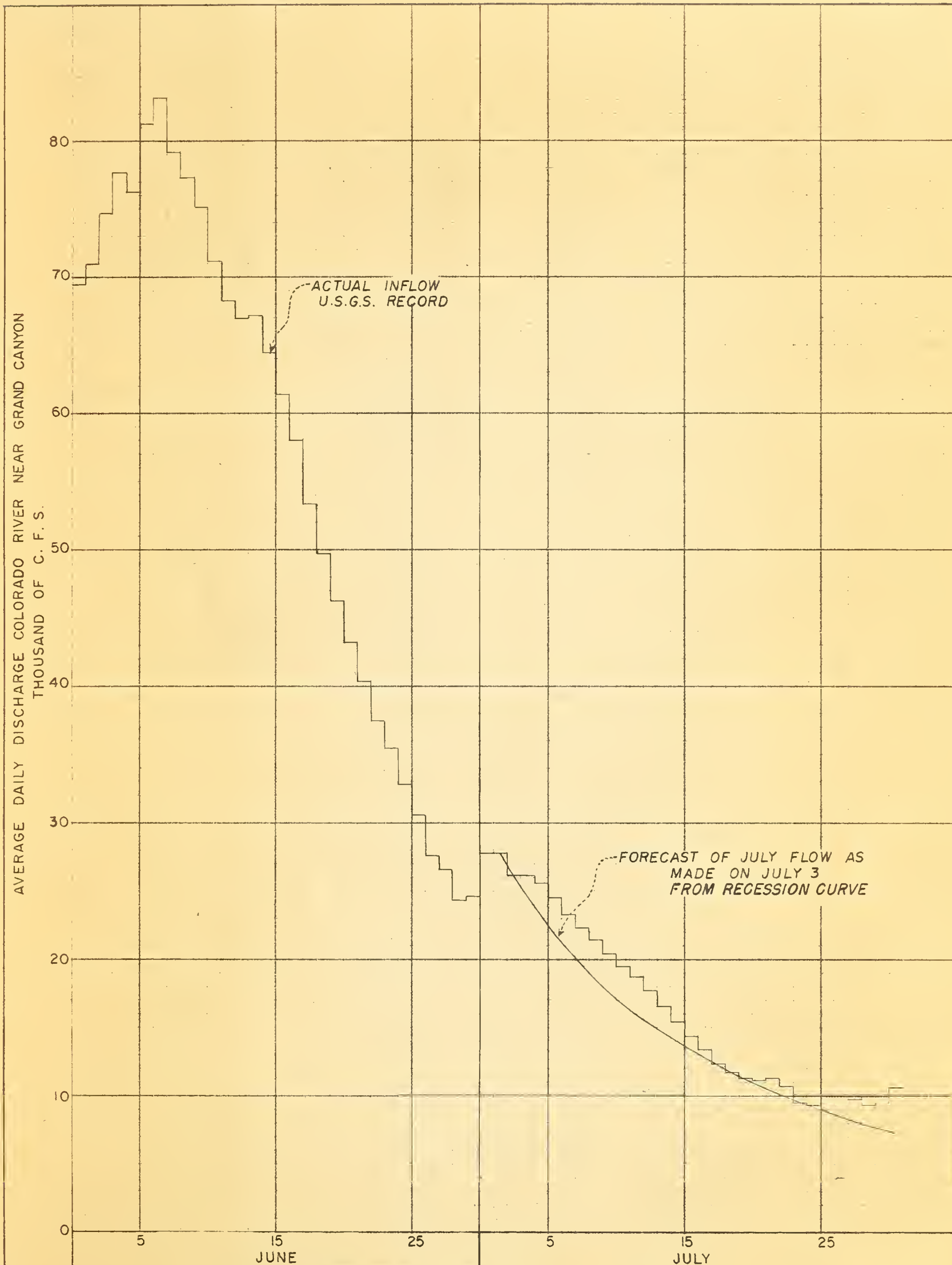
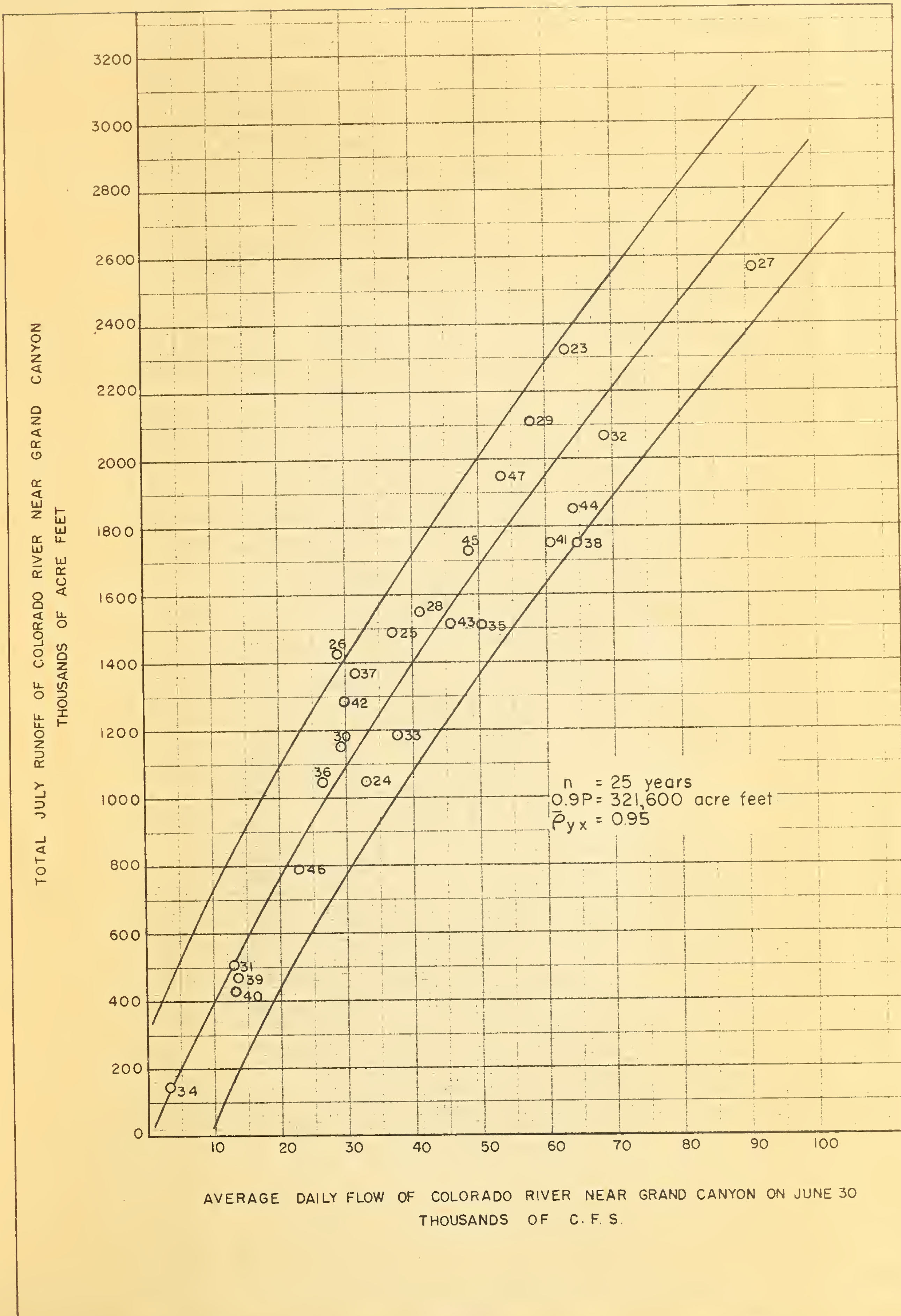
X 1928
⊙ 1927
△ 1941
DISCHARGE 24 HOURS LATER
THOUSANDS OF C.F.S.



HYDROGRAPH
COLORADO RIVER NEAR GRAND CANYON
1948

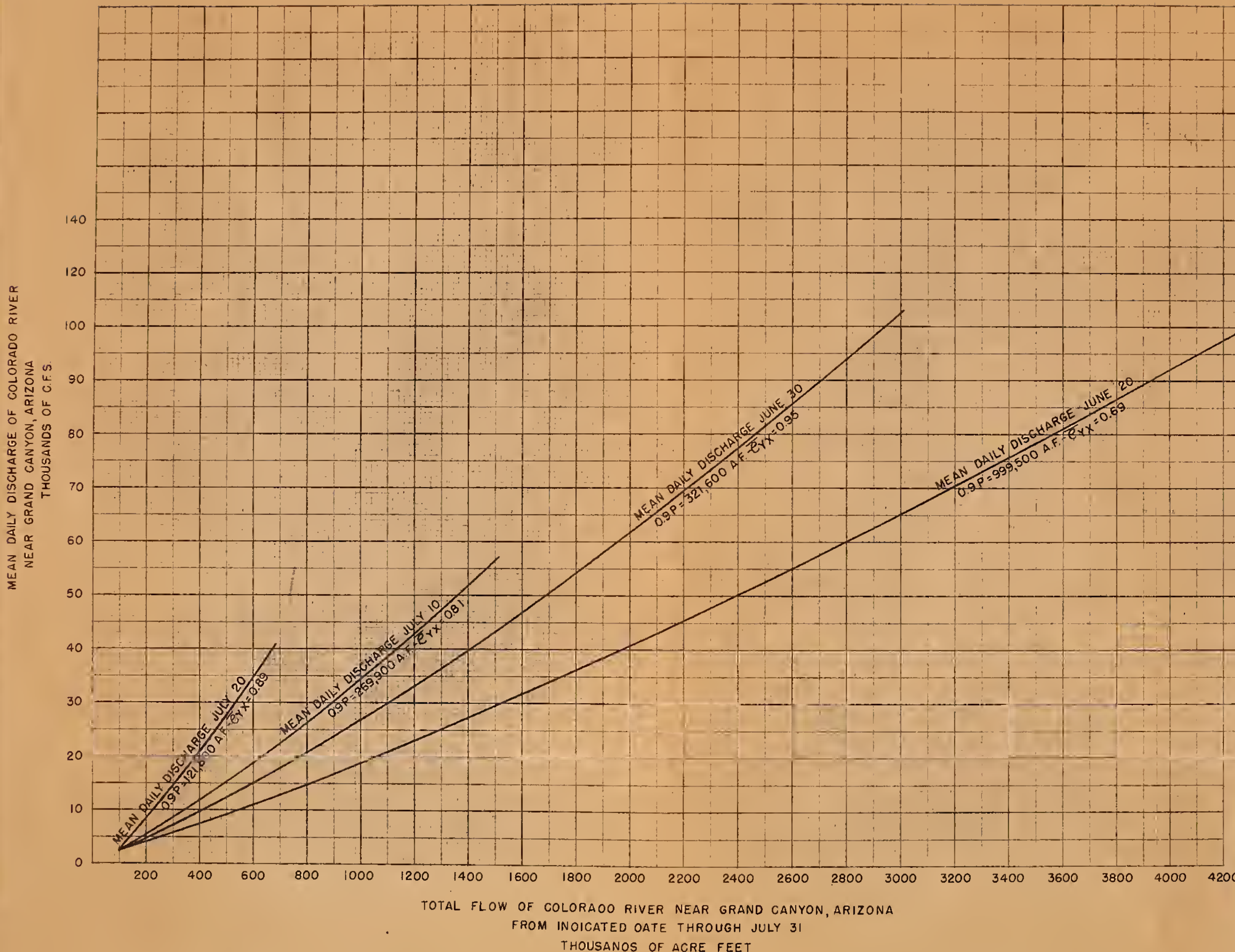
3-28-49 D.E.G.

PLATE 3



TOTAL JULY RUNOFF OF COLORADO RIVER NEAR GRAND CANYON
THOUSANDS OF ACRE FEET
AVERAGE DAILY FLOW OF COLORADO RIVER NEAR GRAND CANYON ON JUNE 30
THOUSANDS OF C. F. S.
n = 25 years
0.9P = 321,600 acre feet
$\bar{\rho}_{yx}$ = 0.95

PLATE 4



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OFFICE OF RIVER CONTROL

FORECAST CURVES FOR COLO. RIVER NEAR GRAND CANYON, ARIZONA

DRAWN: F.R.L. SUBMITTED:
TRACED: G.G.S. RECOMMENDED:
CHECKED: APPROVED:
BOULDER CITY, NEV. 4-1-49

OPERATING WATER AND POWER FACILITIES WITHIN MAXIMUM AND MINIMUM WATER LIMITS

by
Dan Mason

Electrical Engineer

Los Angeles Department of Water and Power - Power System
Power Operating and Maintenance Division
Research and Records Section

Out purpose in discussing the problems encountered in operating Department facilities within maximum and minimum water limits is to show the definite relation of such operation to streamflow forecasting. Since at the present time the Department obtains the major portion of its electrical energy from Hoover Power Plant and it is probably that hydro plants on the Colorado River will continue to be the main source for some time in the future, any factors which might influence the most important source of energy are of considerable interest to the Department. In this paper the preparation of the Department's annual Power System operating schedules will be outlined, with emphasis on the effect of variations in the energy available from Hoover Power Plant in particular.

Energy for supplying the Department's loads is obtained from the following sources:

1 - Department Aqueduct and Owens Valley hydro-plants.
2 - Department steam plants.
3 - Hoover Power Plant.
4 - Other utilities.

Generation at the Aqueduct plants and in part at the Owens Valley plants is governed largely by the water requirements of the City of Los Angeles. Since the water from Owens Valley passes through the Aqueduct plants on its way to Los Angeles, the generation at these plants reflects primarily variations in water requirements, rather than in electric energy requirements. Lower-end reservoirs permit considerable fluctuation in generation and water flow for short periods; however, on an average monthly or annual basis, need for water is the controlling factor in Aqueduct generation.

Water consumption in Los Angeles at the present is such that the Los Angeles Aqueduct must be operated at a rather high annual load factow, thereby increasing operating difficulties, even with the smoothing effect of the lower-end reservoirs. During winter months when the Power System's electric load is high, water requirements in Los Angeles are normally at the low point; during the summer months when water requirements are high, the Power System's load is at its minimum. Whenever it is necessary to take portions of the Aqueduct out of service between Owens Valley and Los Angeles for maintenance work and repairs, the Water System ordinarily would prefer to do so during winter months, just at

the time when the Power System requirements are high. In addition to making it more difficult to supply energy requirements, this also makes it more difficult to provide the necessary generating capacity at the time of the Power System winter peaks.

Although generation at Haiwee Power Plant at the lower end of Owens Valley depends largely upon the required Aqueduct flow, other factors determine the generation at the remaining Owens Valley plants. In a dry year and especially in a series of dry years in Owens Valley, the available surface water supply would set the lower limit. The local Owens Valley electric load and the ability of an interconnected utility to absord electric energy from Owens Valley would fix the upper limit. The energy available from the present Owens Valley plants is only a very small percentage of the Department total; however, the Gorge plants now under construction will in the next few years add a comparatively large block of energy which must be taken into consideration in the preparation of operating schedules.

The second source of energy, generation at the Department's steam plants, can vary within wide limits. The minimum is fixed by the generation necessary to provide capacity for spinning reserve plus some load during peak periods. In addition to generation for energy requirements, it is necessary to have surplus generating capacity connected to the system at all times so that the failure of equipment will not make it necessary to drop load. Steam generating units cannot be operated at zero load, since a definite amount of steam must pass through the turbines at all times while in operation, to prevent undesirable thermal changes with consequent damage to the turbines. Because of this, it is sometimes necessary to generate steam energy as a by-product of providing spinning reserve capacity, when it would be desirable to use Hoover energy instead. The maximum is fixed either by the generation necessary to meet energy requirements (over and above generation at the Aqueduct and Owens Valley plants and the minimum allowable generation at Hoover), or by the plant capability, whichever is smaller.

Generation at the steam plants may be affected by the kind and price of fuel oil available at the time. Oil is the fuel ordinarily used; however, during the summer months natural gas (usually somewhat cheaper on a heat-content basis than oil) may be available in considerable amounts and is used in preference to oil.

Energy from the third source, Hoover Power Plant, can also vary within comparatively wide limits. In addition to variations caused by different amounts of secondary energy being declared, the energy available for transmission to the City is also affected by sales of Hoover energy to Basic Magnesium Project and to the U.S.B.R. for resale to Arizona Utilities. Sales to the latter in particular change a great deal from month to month, being determined largely by irrigation requirements in Arizona.

As explained in the paper presented by Mr. Kaser at the fourth annual meeting of Forecast Committee at Reno, the Office of River Control of the U. S. Bureau of Reclamation prepares forecasts of the Colorado River runoff to be used in operating Hoover Power Plant. The Bureau, in conjunction with allottees of energy at Hoover Power Plant

(including the Department of Water and Power), from time to time during the course of a year determines the energy available at Hoover Power Plant, the amount depending mainly upon the prospective runoff. The Bureau of Reclamation quite properly uses only its own forecast in the determination of the available Hoover energy. Since streamflow forecasting has not yet been advanced to the point at which the Colorado River runoff during the Hoover operating year (June 1 - May 31) can be predicted with a high degree of accuracy at the beginning of the operating year, the Department's operating schedule must of necessity occasionally be revised to meet any changes in available Hoover energy. This last statement should not be considered as a criticism of any regulatory body, since the problem arises not from any policy set by such body, but rather from the inherent difficulty of making highly accurate streamflow forecasts.

Usually a tentative figure for the available Hoover energy is determined by the Bureau of Reclamation near the beginning of the operating year. In setting up the Deparment's operating schedule the possibility of increases in Hoover energy later in the year must always be considered; on the other hand, sufficient energy from sources other than Hoover should be scheduled during the first part of the year so that prolonged unscheduled outages of other plants or large units would not prevent meeting load requirements, even though no additional Hoover energy should be made available.

Generation at either hydro or steam plants will be affected whenever it is necessary to take equipment out of service for overhauls or repairs. The overhaul schedule requires thorough co-ordination with the generation schedule and is subject to periodic revision.

The last source of energy is purchases from other utilities, such purchases ordinarily being made in a year in which only a limited amount of Hoover energy is available. The amount of purchased energy is small compared to total system requirements.

In the operation of Department facilities it is necessary to consider all of the sources of energy and the factors which may affect them. The scheduling of the utilization of energy from the various sources requires careful integration of these sources, if efficient and economical operation is to be obtained.

In the preparation of annual operating schedules the first step is, of course, estimating the system load. Estimating the Department's own system load presents only moderate difficulty; however, sales to other utilities or other large wholesale customers such as the Arizona Utilities just mentioned cannot be estimated accurately. After the load estimates have been completed and a tentative overhaul program has been established, the next step is tabulating, by month, the following:

1 - Generation at the Aqueduct and Owens Valley plants.
2 - Minimum generation at each steam plant.
3 - Increased generation at the steam plants sufficient to utilize the estimated available gas, if any.

4 - Generation for the Department at Hoover Power Plant.
5 - Additional generation at the steam plants, (if needed), sufficient to satisfy system load requirements. The additional generation is scheduled at the most efficient plant first until its full capacity is reached, then at the next most efficient plant, and so on.
6 - Energy purchased from other utilities, if any.

The steam generation and Hoover generation may then be rearranged to some extent if necessary. In a year with a large amount of Hoover energy available it is usually necessary to schedule considerably more Hoover generation per month in the winter than in the summer; unless the Hoover generation is scheduled at a high rate in months when the system load is high it is much more difficult to absorb all the Hoover energy available during the year. Normally in a dry year the Department's Hoover generation would be scheduled at a more nearly constant rate; the amount being smaller, no particular difficulties are presented in its absorption.

When the Department's Hoover generation schedule is completed the estimated schedules of all the other allottees at Hoover Power Plant are combined with that of the Department, and the total is examined to make certain that the water released is sufficient for downstream irrigation requirements; if not, sufficient generation is then shifted from non-critical months to months with high irrigation requirements.

When the Hoover schedule is finally approved by the Bureau of Reclamation it is used as the basis for system operation until the outlook for the Colorado River runoff changes sufficiently to justify a new estimate of Hoover energy by the Bureau. It then becomes necessary to prepare a new operating schedule taking into account any changes in Department conditions and loads, as well as in Hoover energy. It is sometimes necessary to revise the schedule several times during the course of an operating year if runoff prospects improve a great deal as the year progresses, following in general the procedure just described.

If the amount of Hoover energy were definitely fixed at the beginning of the operating year, either at the minimum of firm energy only, or at the maximum with unlimited secondary energy, system operation would be greatly simplified, since the operating schedule could readily be set up to conform with either condition. Under actual operating procedures, however, revisions in the Hoover energy greatly increase operating difficulties, as previously pointed out. To illustrate how the Department's operating expenses may be increased by such revisions, let us consider a hypothetical case, with conditions somewhat like those of the present operating year:

Assume that at the beginning of an operating year, firm energy only is declared available at Hoover Power Plant, the Department's share being approximately 2 billion kilowatt-hours. Assume the system load for the year, (excluding deliveries of Hoover energy to other municipalities), to be 4.5 billion kilowatt-hours. If the estimated Aqueduct and Owens Valley hydro energy is 450 million kilowatt-hours, then the required steam generation would be 2.05 billion kilowatt-hours, (assuming

no purchases from other utilities). With the present steam plants, not all of the required steam energy could be scheduled at high-efficiency plants. Approximately 200 million kilowatt-hours, in addition to the minimum required for spinning reserve and peaking, would have to be generated at plants of medium efficiency. In order to be on the safe side in case no additional Hoover energy should be made available, or in case of a prolonged outage of a large generating unit as a result of breakdown, approximately one-half of these 200 million kilowatt-hours ordinarily would be scheduled for generation during the first half of the operating year.

Assume then that about the middle of the year runoff prospects improve so much that the Bureau of Reclamation releases an additional 500 million kilowatt-hours of Hoover energy to the Department. The steam generation scheduled for the rest of the year would be decreased by a like amount, generation at the plants of medium efficiency being decreased to the minimum first, of course, before the high efficiency plants were unloaded. Thus it would not be necessary to generate about one-half of the 200 million kilowatt-hours above, which had been scheduled at plants of medium efficiency. However, because 100 million kilowatt-hours would have been generated at these less efficient plants in the first part of the year, the Department would have incurred an operating expense which could have been avoided had it been known in advance that additional Hoover energy was forthcoming. Generation of 100 million kilowatt-hours at the Department's high-efficiency steam plants would require the incremental use of about 180,000 barrels of fuel oil; generation of a like amount of energy at plants of lower efficiency would have required at least 230,000 barrels. With oil at $2.00 per barrel the additional cost to the Department of generating the 100 million kilowatt-hours at plants of medium efficiency would have been $100,000.

Uncertainty at the beginning of the year as to the amount of available Hoover energy may cause the Department additional expense in another way. Assume that at the end of March, the Bureau of Reclamation releases to the Department (in addition to the 500 million kilowatt-hours previously mentioned) another large block of Hoover energy, for example: 200 million kilowatt-hours. Assume also that natural gas in an amount equivalent to 200,000 barrels of oil is available in April and May, which if burned at our steam plants would produce 90 million killowatt-hours. In order to use as much of the additional 200 million kilowatt hours of Hoover energy as possible, it would be necessary to reduce generation at all steam plants to the minimum required for spinning reserve and peaking. If the minimum allowable should be 80 million kilowatt-hours, then 10 million kilowatt-hours would have been generated previously using oil which could have been generated using gas in April and May. On an incremental basis the generation of 10 million kilowatt-hours would have required about 18,000 barrels of oil. With oil at $2.00 per barrel, the cost of the gas equivalent would be about $1.50 per barrel. Generation of the 10 million kilowatt-hours using oil would have cost $36,000; using gas the cost would have been $27,000. The Department would therefore have incurred an additional expense of $9,000.

The Department may be affected adversely in still another way in this example because the amount of Hoover energy was not definitely

known in advance. Assume that out of the 200 million kilowatt-hours of additional Hoover energy in April and May, 100 million kilowatt-hours could not be absorbed by the Department, the reason being as follows: During the hours of the day when the Department's system load is high, the use of Hoover energy would be limited to a definite amount by the generating capacity at Hoover: during hours when the system load is low, the use would be limited to the difference between the system load and the minimum allowable generation at other plants. As a result, 100 million kilowatt-hours would have been generated previously using oil which could have been replaced by Hoover energy. The generation of these 100 million kilowatt-hours of steam energy would have required at least 180,000 barrels, costing $360,000. If the 100 million kilowatt-hours could have been taken from Hoover Power Plant, the energy would have been billed at the Hoover secondary rate (approximately 0.5 mills per kilowatt-hour) and the cost to the Department would have been about $50,000. Thus the Department would have been subjected to another additional expense of $310,000.

While the total of the additional expenses in the preceding example is $419,000, the magnitude of additional operating expenses arising from uncertainty as to the amount of Hoover energy which could be expected in any given year would, of course, depend upon the specific conditions in the given year. The example given, while based on conditions similar to those of 1948-49, is not necessarily typical.

In addition to the readily-evaluated items of expense shown in the example, revisions in the amount of available Hoover energy can cause the Department considerable trouble in scheduling equipment overhauls. If units at Hoover Power Plant have been scheduled for overhaul in April and May, and a large additional amount of Hoover energy should be made available in these months, the overhaul of these units ordinarily would be postponed, to permit generating and transmitting as much of the additional energy as possible. This postponement could disrupt the overhaul program for the entire year. Although it might be difficult to assign a definite value to the monetary loss resulting from the rearrangement of the overhauls, in some instances the loss could be considerable. If it should become necessary to overhaul two or more large units simultaneously and to place in operation low-efficiency steam units (normally shut down) in order to have sufficient spinning reserve, the additional expense might be $20,000 to $30,000 per month.

In the future, as the older, less efficient steam plants are replaced by modern installations under our construction program, one of the difficulties, that of avoiding generation on low-efficiency steam units, will be eliminated. Load growth may alleviate the problem of absorbing large amounts of Hoover energy in the last few months of the operating year, even though the minimum steam generation for spinning reserve will be greatly increased as new plants are constructed. The completion of the Owens River Gorge plants or other hydro plants will bring the problem of combining the output of these plants with energy from our other sources. There may be sufficient diversity in the water supply between the Mono-Owens basin and the Colorado River basin to ease the problem of integrating Owens Valley and Hoover generation in most years. With extremely wet conditions existing simultaneously in both basins, however, absorption of all the energy might be quite difficult. It appears that streamflow forecasting will still be of great importance to the Department, even with a much larger percentage of total energy requirements being produced by steam plants than at present.

COMMENTS ON USE OF STATISTICAL METHODS AND OTHER MATHEMATICAL DEVICES IN STREAMFLOW FORECASTING

by

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The first estimates of future streamflow were made by observers after they made a visual inspection of the snow fields and then, in their own minds, correlated depth of snow with runoff. Eventually, the men interested in forecasting streamflow realized that depth of snow did not give accurate results and they began to measure the water content of the snow and made graphical charts of the relationship between runoff and water content of snow. While graphical charts were quite successful for their purpose, their main disadvantage lies in the fact that the same data did not yield similar results for different investigators. This led other investigators to use mathematical techniques such as statistics in determining the relationship between water content of snow and runoff. Application of statistics to the short snow survey records introduced another problem since the reliability of results obtained by statistical methods depends to a great extent upon the length of records used. This problem led other investigators into a search for other variables which would correlate well with runoff and have a long record. Such a variable is precipitation. The science of streamflow forecasting has now developed to the point that statistical techniques are used very extensively. This paper has been prepared to summarize and briefly explain the processes in common usage.

In the development of any streamflow forecasting method it is important that mathematical techniques be used which will eliminate any personal bias. Forecast methods should yield the same results regardless of who is making the forecast and should not depend on the experience of the forecaster. All of the available years of record should be used and those years which appear to be abnormal cannot be eliminated from the analysis solely because of that feature. Statistical analysis of data provide the tools upon which an unbiased analysis of data can be based.

In studying the relationship between rainfall or snowfall, hereafter referred to as precipitation, and runoff, our ultimate purpose should be to arrive at an equation which enables us to forecast runoff from either of the above independent variables. Our forecast equation may be a linear equation either of the simple type $Y = a + bX$ or of the multiple type $Y = a + bX + cX_1 + dX_2$ or it may be a curvilinear equation $Y = a + bX + cX^2$. The type of final equation arrived at should be the one which forecasts runoff with the lowest possible error of the estimate. The discussion in this paper will be confined to linear type equations but all of the techniques discussed can also be applied to curvilinear relationships.

Assuming that a plotting of precipitation against runoff on a scatter diagram shows a relationship between the two variables, we then want to determine the following properties of this relationship:

a. The degree of relationship or correlation between the two variables and its interpretation.

b. The significance of the correlation.

c. The regression or forecast equation.

d. The error of the estimate.

Correlation

The degree of relationship between two variables may be determined statistically by computing the coefficient of linear correlation "r". This computation can be carried out using the following formula:

$$r = \frac{\Sigma(xy) - N(M_x)(M_y)}{\sqrt{(\Sigma X^2 - NM_x^2)(\Sigma Y^2 - NM_y^2)}}$$

X - Precipitation
Y - Runoff
M_Y - Mean of Y
M_X - Mean of X
N - No. of years of record

Coefficients of correlation usually fall somewhere between 0 and ± 1 in size. After the absolute value of "r" has been computed we can see how much it will help us in making our forecast, since that is our ultimate purpose, by use of the following equation $S_y/\sigma_y = \sqrt{1-r^2}$ where S_y = standard error of the estimate of the regression equation, σ_y = standard deviation of dependent variable or runoff. The ratio S_y/σ_y tells us whether the error of the estimate, when we use the regression equation, is relatively large or small as compared with that which we get if we did not use it. For example if r = 0.80 then S_y/σ_y = 0.60 or we have retained 60 percent of the error that we should have had by simply guessing the mean each year or conversely, the use of the regression equation had reduced the error of guessing 40 percent. Figure A illustrates how the ratio of S_y/σ_y varies with values of "r".

Significance of Correlation Coefficient

In determining the correlation between precipitation and runoff, we must always keep in mind that the period we are dealing with is simply a sample, and the only available sample, of all the years gone by (called the universe).

In the case of rainfall and runoff records on the upper Colorado River basin we are dealing with the period 1913-1948 and the 36 years is a very small sample of the hundreds of years gone by. In the case of snow survey records on the upper Colorado River basin, we are dealing

with the period 1936-1948, this period covering 13 years which is only one-third the size of the rainfall-runoff period. Regardless of the length of the period covered, we are faced with the problem of determining whether the value of "r" secured from our sample is significant of a real relationship between the variables (precipitation and runoff) in question in the universe from which the sample was drawn.

American statisticians commonly use as a test of significance the arbitrary rule that the value of the correlation coefficient must equal or exceed its standard error by three times. If the correlation coefficient of the sample is three times its standard error, the chances are 369 to 1 against the occurrence of such a correlation by pure chance. The standard error of the correlation coefficient can be computed from the following equation $\sigma_r = 1-r^2/\sqrt{N-2}$ where σ_r = standard error of correlation coefficient. Ezekiel (1) states that this equation applies when N is 100 or more and Mills (2) states that it may be used when N is 50 or more. Fisher (3) has devised a method for transforming values of "r" to values of Z which are reliable even when computed from small samples. This is very fortunate, for workers in the streamflow forecasting fields are usually forced to compute correlation coefficients for variables with less than 35 years of record, and the Z transformation should always be performed to check the true significance of any correlation coefficient obtained.

The value of Z corresponding to a given value of "r" can be determined from tables, and the standard error of Z can be computed from $\sigma_z = 1/\sqrt{N-3}$. As with correlation coefficients, the value of must equal or exceed its standard error by three times to be considered significant by the above rule.

While we have mentioned that samples with less than 50 or 100 items are to be considered as small samples, it should be remembered that samples with 40 items are more reliable than samples with 10 items.

The Regression or Forecast Equation

If a significant correlation exists between precipitation and runoff in the sample then the points of the two variables when plotted graphically on a scatter diagram, will follow a definite line of movement of "path." The trend or direction of this movement may be defined by a "least squares" line. A straight line fitted by the

(1) Mordecia Ezekiel, "Methods of Correlation Analysis" John Wiley and Sons, Inc., New York, 1941.
(2) F. C. Mills, "Statistical Methods Applied to Economics and Business" Henry Holt and Company, New York, 1938.
(3) R. A. Fisher, "Statistical Methods for Research Workers" Oliver and Boyd, Edinburgh, 1938.

method of least squares is more likely to be right than any other straight line. However, if the basic trend is not linear then the straight line fitted by this method will not be the correct line.

Every straight line has the general form Y = a + bX. The values of "a" and "b" for the line which fits best (the least square line) can be determined by solving, simultaneously, the following two equations:

$$Na + b\Sigma x = \Sigma xy$$
$$a\Sigma x + b\Sigma x^2 = \Sigma xy$$

where N = number of years of record.

The Error of the Estimate

The regression equation is used to estimate a theoretical value of Y for a given value of X. If the relationship is not perfect $(r \neq \pm 1.0$ the actual value will not coincide with the theoretical values, because of the scatter or variation about the least square line. If the scatter is definitely measured the variation may be allowed for and a range established within which a definite percent of values will fall. The measure used for this purpose is called the standard error of the estimate, and can be computed from the following formula:

$$S_y = \sigma_y \left[\frac{N}{N-M}(1-r^2\right]^{1/2}$$

S_y - Standard error of estimate
σ_y - Standard deviation of Y
N - Number of items
M - Number of constants in equation (2 for the equation Y = a + bX)

The significance of the standard error, S_y has been brought out graphically on Figure A.

A least square line has been drawn through the points on Figure B and what may be called zones of estimates have been marked out about this line.

If the distribution is normal, 68 percent of all the points should fall within the zone having a width equal to $2S_y$ or $\pm S_y$. Actually on the chart 24 points of 67 percent of the points are within the zone. On the same assumption 99.7 percent of all the points should fall within the zone having a width equal to 6 S_y or $\pm$ 3 S_y. Actually on the chart, all of the points or 100 percent are within this zone. Also 90 percent of all the points should fall within the zone having a width equal to 3.28 S_y or $\pm$ 1.64 S_y, and on the chart 33 points or 92 percent of the points are within this zone. It can be seen then that the observed percentage of points within any zone agree closely with the computed percentage and hence our distribution is about normal.

The above simply means that if $\pm$ S_y is used for forecasting purposes; one can expect, on the average, that in the future in 68 percent of the cases, the actual value will fall within the range of the forecasted

value ± Sy. If ± 3 Sy is used, then in the future in 99.7 percent of the cases, the actual values will fall within the range of the forecasted value ± 3 Sy.

Use of one standard error does not give enough protection to the user of the runoff forecast because, on the average, one time out of three, the actual value will fall outside of the range. The use of three standard errors, while guaranteeing the user that the actual value will fall within its range 997 times out of 1000, is too large a range. For example, in the above chart 3 Sy is 5.6 m̄.a.f. and the range of any forecast would be 11.2 m̄.a.f. The Office of River Control has decided on a range of nine out of ten and use of a standard error of 1.69 Sy for 34 degrees of freedom will yield such a range.

Multiple Correlation

Up to now we have concerned ourselves with problems involving only two variables, a dependent variable such as runoff and a single independent variable such as precipitation. But it is obvious that, in general, runoff is affected by more than one factor, and may be due to the interaction of many forces such as temperature, soil moisture, antecedent precipitation, and other factors. The measurement of the relationship between a dependent variable and two or more independent variables is known as multiple correlation and the coefficient of multiple correlation is designated by R. The estimating or regression equation in the case where there is a single dependent variable and three independent variables will be of the form

$$Y = a + bX_1 + cX_2 + dX_3$$

Where Y - runoff
X_1 - precipitation
X_2 - temperature
X_3 - antecedent precipitation

The method of least squares affords the means of solving for the required constants. The coefficients of X_1, X_2, and X_3, indicate the net relationship between the dependent and an independent variable, allowing for the other factors or variables which are also considered in the equation.

A multiple correlation between runoff and all the factors influencing it such as temperature, antecedent precipitation, prior runoff, soil moisture and carry over effect, may not necessarily raise the value of the correlation coefficient from that obtained by a simple correlation between runoff and precipitation. This may be due to the fact that while we have tried to include all of the factors causing runoff in our correlation, we have not selected the proper sample of each variable. For example, for the temperature variable, we may use the average winter temperature (Dec. through Feb.) of five stations in the basin. Maybe those five stations do not yield the winter temperature related to runoff, or the winter period selected is not related to

spring runoff. It can be seen that if we are to obtain an improved correlation coefficient from a multiple correlation we must continually search for the proper combination of variables and select the correct sample of each variable.

One disadvantage of multiple correlations is the loss of "degrees of freedom." Degrees of freedom may be defined as the number of observations minus the number of constants determined. In the case of a simple linear correlation the degrees of freedom is equal to the number of observations minus two.

The standard error of the estimate may be computed from the following equation $S_y = \sigma_y [N/N-M(1-r^2)]^{\frac{1}{2}}$ where N-M equal the degrees of freedom. It can be seen that an increased value of the correlation coefficient due to an increase in the number of independent variables may not necessarily decrease the value of the error of the estimate because of a loss in degree of freedom. This is especially so where the number of items (N) is small and can be illustrated in the following example: Let us assume Y to be the same dependent variable in a simple and multiple correlation and hence σ_y will be the same. If we let the correlation coefficient (r) of the simple correlation be 0.80 and N = 15, then $S_y = 0.64\ \sigma_y$ for the simple correlation. Now if we increase the number of independent variables from two to four, the value of R needed for the multiple correlation to yield a like value for S_y is 0.84. If N = 50 and r = 0.80 then for the simple correlation $S_y = 0.612\ \sigma_y$ and the value of R needed for the multiple correlation to yield a like value for S_y is 0.809. It is to be noted from Figure A that after "r" reaches a value of about 0.80, small increases in its value produce a decided reduction in the ratio of S_y/σ_y. Hence any valid adjustment of the data which will increase the value of "r" above 0.80 is worthwhile.

Tests of the significance of differences

It has been shown that the significance of a correlation coefficient may be tested by determining its standard error or by performing the Z-transformation. Another problem which frequently arises in streamflow forecasting is the determination of the significance of a change in the value of a correlation coefficient. For example if one group of years yields an r_1 of 0.80 and another group of years yields an r_2 of 0.85 it is important to know whether this increase in the value of "r" is due to chance or actually to an improved relationship between the variables.

To determine t e significance of the difference between two values of one converts the values of r_1 and r_2 to Z_1 and Z_2 and also computes the values of and . Then the standard error of the difference of "r" is computed from the following equation $\sigma_{z_1 - z_2} = \sqrt{\sigma_{z_1}^2 + \sigma_{z_2}^2}$. If the difference between the value of Z_1 and Z_2 is three times the value of $\sigma_{z_1 - z_2}$ the difference between the values of "r" can be considered as significant.

It should be pointed out that the above test for the significance of a change in "r" may yield misleading results when one is trying to improve the value of "r" in a sample by the addition of more variables

or by manipulation of the data. For example, let us assume that the correlation coefficient between precipitation and streamflow in a particular sample is 0.85. If the standard deviation σ_y of the streamflow variable is 3.000 and the number of items is N = 25 then the standard error of the estimate S_y = 1.65.

Now if the correlation coefficient of this sample could be increased to 0.90 and σ_y = 3.000 and N = 25, then S_y = 1.39. Yet according to the above test of significance the change in "r" from 0.85 to 0.90 would not be considered significant.

However the relationship yielding the improved value of "r" would be used even though the change in the value of "r" would not satisfy the statistical test of significance. One argument for adopting the second method would be that it had equal chance of being right as the first method, and should not be penalized merely because it did not receive the first trial.

Double Mass Diagrams

The double mass diagram has been found to be a useful device in the detection of inconsistencies in both streamflow and precipitation records. The diagram is constructed by the plotting accumulatively of one set of data against another. In studying streamflow records, one first determines the correlation between rainfall and runoff. From this correlation it is possible to convert from actual rainfall to the runoff that the actual rain would have been expected to produce. This expected runoff may then be treated as though it were real and may be compared with the observed runoff by accumulation and plotting against accumulated actual runoff.

Some investigators use the technique of plotting the accumulated precipitation pattern for a basin against the accumulated runoff. There are a few disadvantages to this particular technique, namely:

(a) Misleading results will be obtained if a non-linear relationship exists between precipitation and runoff.

(b) Breaks are sometimes obtained in double mass curves of this type because the relationship between runoff and precipitation is not a simple ratio.

These breaks may be eliminated by first plotting runoff against precipitation and then fitting a curve to the data. The intercept on the precipitation axis is then subtracted from each value of precipitation and the break in the double mass curve will disappear if it was originally due to the fact that the original relationship was not a simple ratio.

The double mass curve which results from a plotting of accumulated computed runoff against accumulated observed runoff will be straight unless one of the following conditions has occurred which may cause a bend in the curve:

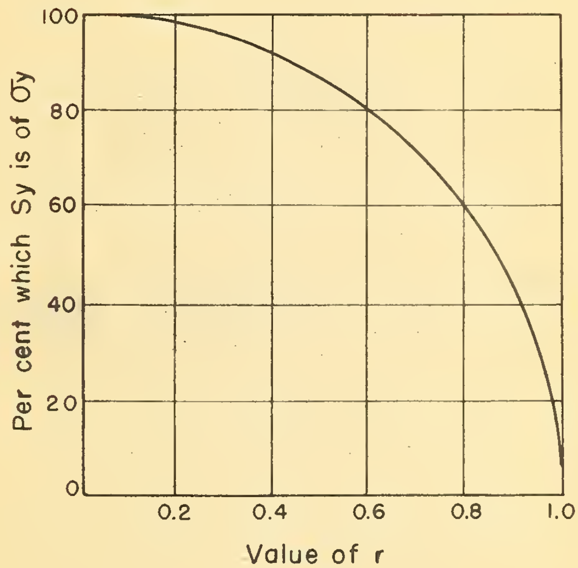
(a) There has been a change in the location of the streamflow measuring device.

(b) The type of streamflow measuring device has been changed from a staff gage to a continuous water stage recorder.

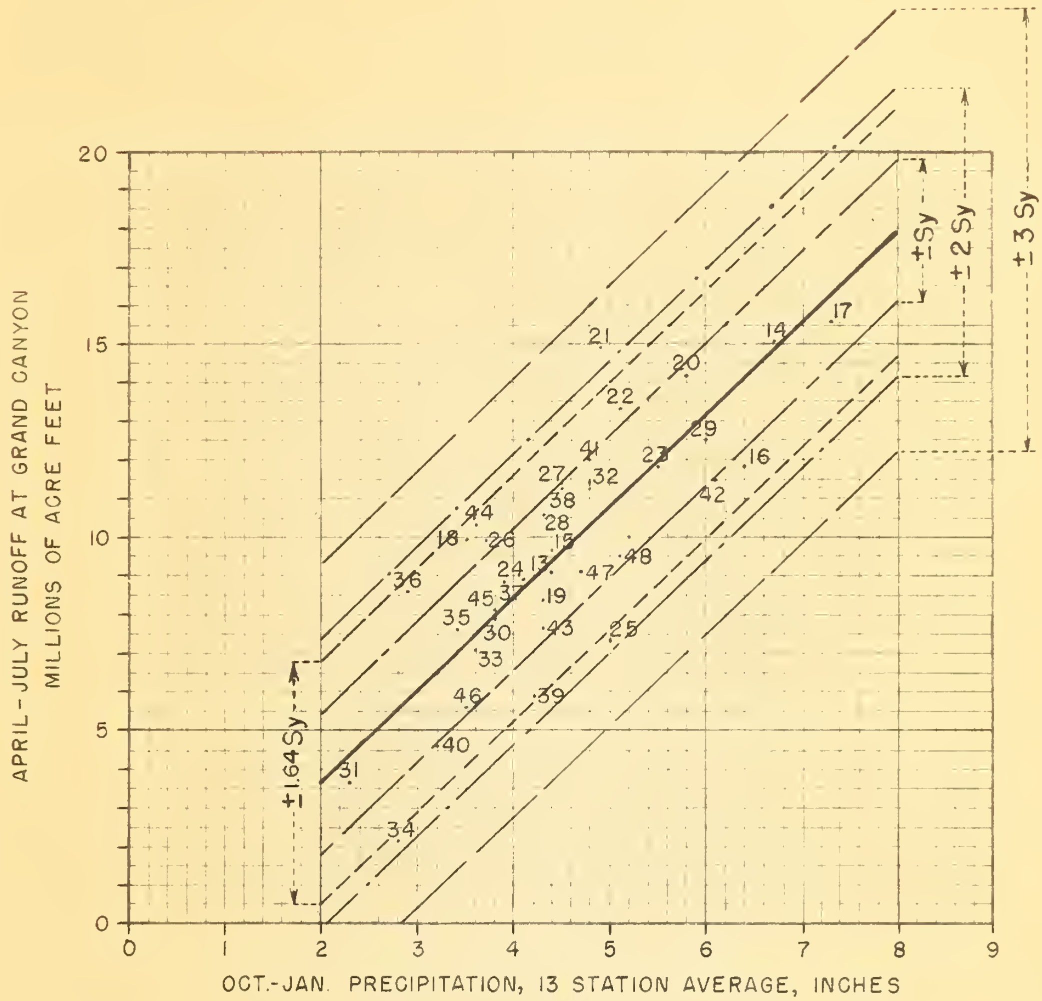
(c) The observed streamflow record is partly estimated.

(d) There are a succession of years in which the expected runoff is more than the observed runoff and then a succession of years which the expected runoff is less than the observed runoff. Breaks due to such a condition are fictitious. This condition was encountered in a study of the Colorado River at Lees Ferry.

FIGURE A



Percentage which the standard error of estimate is of the standard deviation when the coefficient of correlation has various values.



r = 0.8014 ± 0.16
y = 2.37X − 1.00
n = 36
0.9P = ± 3.2 m.a.f.
Sy = ± 1.9

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
REGION 3

OFFICE OF RIVER CONTROL
CHART FOR FEBRUARY 1
FORECAST

RC-3-221 M. D. W. L. P.

WATER PROBLEMS ON INTERNATIONAL STREAMS

by

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Office of River Control, International Boundary Commission

When your program chairman, Mr. Stockwell, invited a representative of the United States Section, International Boundary and Water Commission, United States and Mexico, to speak before this meeting on the subject of needs for runoff forecasts on international streams, our immediate reaction was that the needs for forecasts on international streams were essentially no different than the needs for forecasts on other streams. It was, of course, obvious that your interest was in learning something about the particular problems confronting our agency. I hope that in these remarks I shall be able to show you briefly our principal concern with forecasts of river discharge.

Before going further, let me convey to your program chairman and to the entire assemblage that Commissioner Lawson extends his greetings and regrets that commitments involving the joint work with Mexico, under the Water Treaty of 1944, prevent his being present today. I am privileged to represent our organization and know that in being permitted to attend this meeting I will be able to learn something more of your problems and the techniques used in solving them.

The International Boundary and Water Commission, United States and Mexico, is concerned with the flow of three principal streams: the Rio Grande, the Colorado River, and the Tijuana River. The Water Treaty of 1944 between the United States and Mexico is concerned with these three streams. There are other rivers crossing the border, principally in Arizona, involving some international problems. To avoid unnecessary detail, I am omitting any comment on these minor streams. As a matter of fact, I think I can dismiss the Tijuana River, for the purposes of this meeting, with the comment that the Water Treaty of 1944 provides that the Commission shall study and investigate and shall submit to the two governments, for their approval, recommendations for the equitable distribution between the two countries of the waters of the Tijuana River system, including plans for the control, development, and utilization of these waters. This study is presently under way and the United States portion is being carried forward under the supervision of our San Diego office. For the time being, we are trying to ascertain what past flows have been and what the various tributaries have yielded. As yet we have no need for forecasts on this river.

The Water Treaty allocates to Mexico 1,500,000 acre-feet of the water of the Colorado River as a guaranteed minimum except in the event of extraordinary drought or serious accident to the irrigation system in the United States. Under the Treaty, with one exception, all waters allotted to Mexico are to be delivered wherever they may arrive in the bed of the international section of the Colorado River. As you know, the international reach of the Colorado River extends for twenty miles

between Arizona and Mexico, south from the California border to the southern border of Arizona. The exception as to the location of delivery of water is through the All-American Canal and through the Alamo Canal or such other Mexican canal as may be substituted for it.

The Treaty also provides for the construction, by Mexico, of a diversion dam south of the California border. This structure, named the Morelos Dam, is now being built about a mile below the California border, near the Mexican community of Andrade.

The Water Treaty provides that the two nations, working through their Sections of the Commission, will devise plans for the control of floods on the portion of the river downstream from Imperial Dam. A study to this end is now under way with the United States Section having primary responsibility for the international portion of the stream and the Mexican Section being primarily responsible for the reach extending south of the Arizona boundary to the Gulf.

Under these responsibilities, it appears that three types of estimates of flow of the Colorado River are needed by the International Boundary and Water Commission. First, in connection with the design of flood control works, it will need to know what the maximum expected peak discharge below Imperial Dam will be. This figure will presumably be based upon estimates of the Bureau of Reclamation on the basis of its control of the Colorado River as affected by the Gila River upon which flood control works are currently under consideration by the Corps of Engineers. Secondly, forecasts will be needed in the nature of flood warnings to advise when any irregular flow is expected so that necessary steps may be taken properly to operate and safeguard the diversion dam, diversion works, and the downstream portion of the river together with its protective works. Finally, it will be necessary to know early each season the quantity it will be feasible to deliver to Mexico, under the Water Treaty. This is necessary, particularly as Mexico's demands approach the maximum of the allotment, so that that nation can plan a schedule for deliveries to its several diversion points. When Davis Dam is completed, it is expected that principal control of deliveries to Mexico will be effected through that structure.

Basically, the situation on the Rio Grande is essentially the same; details, of course, vary. Under the Convention of 1906, between the two nations, 60,000 acre-feet of Rio Grande water is allotted to Mexico at Juarez. In the event of extreme drought, this quantity is to be reduced in the same proportion as is the allotment of water to the Bureau of Reclamation Rio Grande Federal Project. The control of this delivery is effected primarily by Elephant Butte and Caballo Dams. The American Dam at El Paso, under the jurisdiction of the International Boundary and Water Commission, diverts to a canal water for the Reclamation project and releases to the Rio Grande channel flows for delivery to Mexico. These latter, in turn, are diverted to Mexico at an international dam a short distance further downstream. In this upstream portion of the international reach of the river, between El Paso and Fort Quitman, we are also interested in forecasts of floods so that necessary warnings can be made and precautions taken.

At Fort Quitman the river, for all practical purposes, plays out. A large volume of the flow has been consumed in irrigation; return flow is relatively small, and has a rather high content of dissolved salts. The stream is, in effect, revived near Presidio where the Conchos River enters from Mexico. Continuing downstream, the Pecos and Devils River join from the United States side, followed by several small streams; then approaching the delta area, Rio Escondido, Rio Salado, Rio Alamo and Rio San Juan enter from Mexico.

Under provisions of the Water Treaty of 1944, all the flow from certain United States tributaries, one-third of that from certain Mexican tributaries, and one-half of the remainder in the river is allotted to the United States; the balance is allotted to Mexico. Control works provided for by the treaty consist of a storage dam at Falcon, one near the Big Bend region, and possibly one between the two. At least one diversion dam will be built under authority of the Treaty. We are here faced once again with a typical flood warning forecast problem and to some extent a yield forecast problem. More important, however, in the international operation of the structures will probably be the water accounting problem to determine the ownership of waters in the river and in the reservoirs. Since the ownership of waters in the reservoir will vary, dependent upon the contributions of the various tributaries, a calculation of some complication is involved. Then, because we cannot expect that the two nations will consistently withdraw their water from storage at the same rate, determining the ownership at any particular time will involve further calculations which must be made to the satisfaction of each of the two countries.

A continuing reporting system will be necessary so that water users will have an estimate of the amounts available to them in the periods in the immediate future, as well as the more precise amounts of use and status of actual flows.

This covers briefly the major interests of the International Boundary and Water Commission in forecasts of discharge on the Colorado River and on the Rio Grande. Naturally, in the time allotted, I have made no attempt to give details of the various continuing problems with which we are faced. Rather, I have directed these remarks to the specific forecasting aspects of our problems. I will be glad to answer any questions, to the extent I am able and within the limits permitted by the chair, in the period set for discussion of this subject.